Environmental Studies No.55

Sewage Waste Discharge to the Arctic Marine Environment

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Le premier but de cette étude était de fournir un ensemble de données pour aider à préciser les principaux problèmes environnementaux liés au déversement d'eaux usées dans l'environnement marin de l'Arctique. L'autre but principal était de rassembler des connaissances sur les différentes options de traitement des eaux usées adaptées aux conditions particulières de l'Arctique et de l'Extrême-Arctique.

L'étude comportait les activités suivantes :

1. Collecte, examen et synthèse de données sur les méthodes, les lignes de conduite et les règlements actuels concernant le traitement et l'élimination des eaux usées dans les eaux intérieures ou marines du Canada;

2. Collecte, examen, évaluation et synthèse de données sur l'efficacité et l'utilité des méthodes de traitement des eaux usées (permettant de desservir jusqu'à 125 personnes) en usage actuellement à proximité d'eaux intérieures ou marines du Canada, qui pourraient être appliquées aux activités industrielles extra-côtières dans le Nord;

3. Collecte, examen, évaluation et synthèse de données sur l'efficacité des méthodes de traitement des eaux usées (permettant de desservir jusqu'à 250 personnes) actuellement en usage au Canada à proximité d'eaux intérieures ou marines et dans des installations côtières, qui pourraient être appliquées dans des camps et des bases situés sur les côtes, dans le Nord;

4. Collecte, examen et synthèse de données sur les répercussions environnementales à court et à long terme du déversement d'eaux usées traitées et non traitées dans l'environnement marin de l'Arctique, en accordant une attention particulière : aux emplacements des plages récréatives; aux secteurs visés par la pêche commerciale ou intérieure et les activités de pêche des autochtones; et aux milieux fragiles de l'environnement;

5. Établissement et prestation de renseignements ci-dessus, de recommandations sur le déversement d'eaux usées dans l'environnement marin de l'Arctique pendant de courtes périodes ou à long terme;

6. Établissement et prestation de renseignements sur les méthodes optimales primaires et secondaires de traitement qui peuvent être utilisés efficacement et utilement (compte tenu de la rentabilité) dans le Nord, de façon saisonnière ou à longueur d'année.

Des recommandations on été formulées dans deux domaines : les lignes de conduite et les lignes directrices de réglementation et les techniques de traitement des eaux usées les mieux adaptées au milieu.

LIGNES DE CONDUITE ET LIGNES DIRECTRICES DE RÉGLEMENTATION

Les lignes de conduite de réglementation concernant le déversement des eaux usées dans l'environnement marin arctique ont fluctué au cours des 10 dernières années. On a constaté d'abord de façon générale une pénurie de bons résultats de recherche, sur lesquels on puisse fonder les lignes directrices. En outre, jusqu'au milieu des années 70, il y a eu peu d'activités industrielles dans l'Arctique, de sorte qu'on n'a pas eu tellement besoin d'établir de programmes appropriés de recherche ou des lignes directrices sur les effluents.

À l'heure actuelle, il est particulièrement opportun d'élaborer de telles lignes directrices sur les effluents déversés dans les eaux marines arctiques car la production commerciale de pétrole et de gaz à partir des réserves est inévitable. On a élaboré à cet égard les recommandations suivantes :

1. Dans certains cas, en particulier lorsqu'il s'agit de bateaux de forage, il semble prudent de maintenir les lignes de conduite actuelles permettant le déversement direct d'eaux usées brutes, après leur macération. Comme nous l'avons mentionné plus tôt, les répercussions sur l'environnement seront vraisemblablement négligeables, en particulier à cause des quantités relativement faibles libérées par chaque bateau.

2. Dans le cas des installations extra-côtières et des installations situées sur les côtes, il semble prudent de se conformer aux directives intitulées "Guidelines for Municipal Type Wastewater Discharges in the Northwest Territories". Ces lignes directrices précisent que, pour les déversements d'effluents dans la mer, il faudrait appliquer la ligne directrice suivante :

   > "L'étude d'un site peut s'avérer nécessaire pour les déversements d'effluents dans la mer lorsque des eaux des types suivants risquent d'être affectées : habitats de crustacés, frayères, eaux très fréquentées par les mammifères marins, eaux utilisées pour les loisirs et eaux confinées. Une telle étude sera aussi nécessaire lorsque les objectifs visés exigent l'installation d'un long tuyau de déversement ou qu'on se propose d'éliminer des boues au moyen de celui-ci. Dans les cas où entre en ligne de compte la délimitation des conditions marines et des conditions d'estuaire, on doit déterminer la longueur du tuyau à utiliser en fonction du lieu de déversement en procédant à des études des courants et des études sur la dilution."

3. Lorsque l'étude de l'emplacement indique la nécessité de procéder à un traitement des effluents plus poussé que la simple macération, afin de protéger l'environnement visé, il faudrait que les directives exigent un minimum de traitement secondaire, comportant la désinfection, s'il

existe des préoccupations sérieuses en ce qui a trait à la santé humaines.

4. Dans ces lignes directrices sur le traitement secondaire, on doit insister sur l'utilisation des "meilleures techniques possibles" plutôt que d'établir des limites particulières sur les effluents. Autrement dit, il faut que les organismes de réglementation fassent office de catalyseurs en favorisant l'utilisation de normes de conception pertinentes pour la détermination de la taille des installations de traitement, la sélection et la conception des procédés de traitement, l'élaboration de programmes régionaux de formation sur le fonctionnement des installations et la collecte et l'examen de données sur le fonctionnement de celles-ci. On pourrait réaliser ces objectifs en élaborant des outils comme un guide de normes et de conception pour le traitement des eaux usées et l'élaboration et la prestation d'un programme régional de formation des opérateurs d'installations de traitement des eaux usées situées dans l'Arctique. Le document Cold Climate Utilities Manual (Smith, 1986) fournit les données de base d'un bon guide de conception. Les études ont montré que, lorsqu'on inclut certains éléments essentiels dans la conception des installations de traitement et qu'on fournit en permanence aux opérateurs des directives sur le contrôle des installations, il est possible dans la plupart de celles-ci de retirer les matières organiques et les matières en suspension dans une proportion de 90 à 95 p. 100 ou plus.

5. Lorsque la seule préoccupation environnementale est le risque de contamination par des organismes pathogènes, il faut réaliser un traitement secondaire complet avant d'assurer la désinfection des eaux, habituellement par chloration. On recommande de procéder ainsi car autrement la désinfection des effluents bruts ou primaires s'avère inefficace du fait que la plupart des bactéries et des virus demeurent à l'intérieur des matières solides en suspension.

6. Comme la chloration soulève la question de la toxicité pour les eaux dans lesquelles on déverse les effluents, nous suggérons d'imposer, lorsqu'on exige la chloration, une limite quant à la concentration de chlore permise dans les effluents. Par exemple, dans la réglementation sur les Grands lacs, on a utilisé une limite de 1.0 mg par litre.

MEILLEURES TECHNIQUES POSSIBLES DE TRAITEMENT DES EAUX USÉES

Les méthodes de traitement des eaux en usage dans l'Arctique vont de l'absence de tout traitement à un traitement terciaire complet avant leur déversement dans l'environnement. La forme de traitement la plus couramment utilisée à l'heure actuelle est le dégrillage ou la macération des eaux usées brutes, suivie de leur transfert dans des bassins de rétention en prévision de leur déversement ultérieur dans l'environnement.

Les bassins de stabilisation, surtout de types anaérobique et facultatif, se rencontrent aussi assez couramment dans l'Arctique. Ils sont simples et

relativement peu coûteux à faire fonctionner et permettent le traitement d'eaux usées présentant différentes caractéristiques et différents débits. En outre, lorsqu'ils ont les dimensions appropriées, ils permettent d'obtenir des eaux usées d'une assez bonne qualité. Leur utilisation se limite évidemment aux camps de travail et aux collectivités situées sur la terre ferme.

Les installations mécaniques de traitement des eaux usées, et plus particulièrement les petites installations indépendantes, sont utilisées principalement dans les camps de travail liés aux activités principalement dans les camps de travail liés aux activités pétrolières d'exploration et de production en mer et sur la terre ferme. Les méthodes les plus couramment utilisées sont la stabilisation par contact, l'aération prolongée, la technique des disques biologiques et le procédé physico-chimique. Toutes ces méthodes ont certains éléments en commun, qui font qu'elles sont particulièrement adaptées aux applications auxquelles sont destinées :

1. le matériel utilisé est relativement compact, de sorte qu'il peut être facilement acheminé vers un endroit donné, à titre d'unité complete; et

2. lorsque ces méthodes sont appliquées de façon appropriée, elles permettent de réaliser le traitement secondaire et même, dans certains cas, le traitement tertiaire complet des eaux usées.

Lorsqu'on utilise des installations de traitement biologique pour le traitement secondaire des eaux usées, on doit prévoir au niveau de la conception les éléments suivants :

1. Il faut inclure, dans les plans des installations, des réservoirs aérés de compensation, en raison de leur importance pour la stabilité de celles-ci; on a aussi suggéré de donner aux bassins la taille nécessaire pour absorber 50 p. 100 du débit quotidien;

2. Les installations doivent aussi avoir la taille requise pour traiter les volumes et les densités prévus d'eaux usées;

3. If faut que tous les systèmes de traitement comporte des dispositifs appropriés de maniement et l'élimination des boues;

4. La taille des clarificateurs doit permettre de faire face aux crêtes importantes dans les quantités caractéristiques d'eaux usées déversées dans les installations des camps de travail. Les clarificateurs qui se sont avérés les plus satisfaisants sont ceux qui permettent d'absorber un débit de 2,5 fois le débit quotidien moyen;

5. If faut abriter les installations de traitement mécanique dans un bâtiment de façon à les protéger contre le gel, cette précaution visant aussi bien à maintenir l'efficacité du processus qu'à protéger le matériel et les structures mécaniques;

6. Il faut prévoir, dans le cadre des plans et de l'acquisition des installations, l'achat et la conservation sur place d'éléments clés tels des moteurs, des pompes, des surpresseurs et des roulements à bille; et

7. La conception des installations indépendantes doit permettre de les transporter facilement par avion sur leur lieu de destination.

Pour les installations de traitement des eaux usées situées dans l'Arctique, Smith (1986) a souligné la nécessité d'accorder une attention particulière aux facteurs du fonctionnement et de l'entretien, au cours des étapes du choix et de la conception du processus à utiliser. Voici les exemples qu'il citait à cet égard :

1. If faut disposer de systèmes d'alarme pour signaler les arrêts du processus de traitement, comme dans les cas d'interruption du courant, de trop-plein d'un réservoir, d'accumulations excessives de boues, etc.;

2. On doit assurer une bonne circulation d'air et une bonne répartition de la chaleur à l'intérieur des espaces fermés et chauffés, afin de réduire au minimum les risques de gel localisé;

3. Il faut accorder l'attention voulue aux épaisseurs de glace et de neige attendues pendant l'hiver, afin d'assurer l'accès facile à tous les composantes essentielles des installations;

4. Les installations utilisées de façon intermittente doivent être protégées pour l'hiver;

5. If faut protéger le matériel électrique de tout grillage dû à des pannes de courant ou des variations dans le voltage; et

6. Les panneaux de contrôle et les interrupteurs vulnérables doivent être isolés de l'atmosphère chargé d'humidité des installations de traitement, afin d'éviter toute défectuosité de fonctionnement due au givre ou à la corrosion chimique.

De façon générale, en raison des longues mesures nécessaires au démarrage, les processus de traitement biologique ne conviennent pas aux installations appelées à fonctionner seulement un ou deux mois à la fois. Dans ces cas, il est préférable d'utiliser des installations de traitement physico-chimiques car ils n'exigent pas de périodes de démarrage.

Outre les processus de traitement le plus couramment utilisés, nous avons aussi fait rapport sur l'évaluation et, dans certains cas, l'essai sur place et l'application d'options de traitement des eaux usées offrant un potentiel spécial pour l'Arctique et l'Extrême-Arctique. On peut classer ces options de façon générale en deux catégories :

1. Les processus permettant de tirer un parti maximal de l'environnement d'acceuil pour assurer le traitement des eaux usées; et

2. Ceux visant à utiliser directement les ressources contenues dans les eaux usées.

On peut citer comme exemples de la première catégorie :

1. épandage à la surface sur le sol, en particulier dans les endroits où l'on trouve des sols bien drainés et de texture grossière;

2. élimination dans la toundra à longueur d'année;

3. traitement aux moyen de fosses septiques et de dispositifs souterrains d'élimination comme des champs d'épuration, des fosses d'écoulement des jus ou des filtres intermédiaires, aérobiques ou anaérobiques;

4. déversement direct sur des terrains forestiers ou des terrains marécageux afin de permettre la décantation des matières nutritives et leur absorbtion par les plantes; et

5. injection des eaux usées dans le caisson vertical d'échappement des turbines à gaz ou à combustible liquide.

Les approches innovatrices pour l'exploitation du potentiel des eaux usées comprennent notamment les suivantes :

1. réutilisation de l'eau des effluents traités pour les ateliers, les toilettes ou la dilution des eaux de forage;

2. traitement mécanique au moyen du processus d'oxydation à l'air humide, afin d'assurer le recyclage de l'eau et la récupération de la chaleur dégagée par le processus; et

3. ulilisation de la technique de la pellicule d'éléments nutritifs, un système hydroponique modifié qui fournit de la chaleur réutilisable et permet d'obtenir une eau d'une grande pureté au moyen de processus d'évaporation et de transpiration.

Du point de vue opérationnel, les exigences principales pour assurer le bon fonctionnement des installations de traitement sont le choix d'opérateurs consciencieux et la prestation à ceux-ci de programmes permanents de formation. Dans les installations de traitement des eaux usées de l'Arctique, les problèmes qu'on trouve le plus couramment sont les suivants :

1. sensibilité des porcessus aux fluctuations importantes de débit et de densité des eaux usées;

2. corrosion et autres problèmes entraînés par le taux élevé d'humidité par suite de la nécessité d'enfermer les installations de traitement dans des bâtiments pour les protéger des rigueurs de l'hiver;

3. accumulation de neige et de glace sur les bâtiments, le matériel de contrôle, les voies d'accès et les murs;

4. fraicheur excessive et gel dans les bassins d'aération et les clarificateurs non protégés;

5. omission de racler de façon régulière les clarificateurs à trémie;

6. omission de faire fonctionner le dispositif de retour des boues;

7. temps de fonctionnement insuffisant des surpresseurs dans les systèmes à boues activées; et

8. exploitation des installations par des employés non qualifiés et peu motivés.

L'expérience de l'utilisation de procédés de traitement des eaux usées dans l'Arctique a montré que, lorsqu'on se sert de procédés de traitement mécaniques, il est absolument essentiel de disposer de bons programmes de formation des opérateurs et d'effectuer des vérifications fréquentes des installations, pour en assurer le fonctionnement satifaisant. Le système décrit par Pollen (1985) prévoit la surveillance opérationnelle sur place chaque jour d'un certain nombre d'installations d'une région, la prestation de deux fois par année d'un programme de formation des opérateurs et le contrôle mensuel de la qualité des effluents. L'auteur rapporte que cette approche à trois volets permet de réaliser dans chaque cas une qualité d'effluents conforme aux exigences imposées aux installations.

Il n'est pas nécessaire que la teneur des programmes de formation des opérateurs s'appliquant à L'Arctique soit sensiblement différente de celle des programmes dispensés dans le sud du Canada, à une exception près. Il faut en effet mettre l'accent sur les exigences et les problèmes particuliers de fonctionnement propres à l'hiver. La façon la plus efficace d'assurer la formation des opérateurs est de faire appel à des sessions structurées de cours en salle de classe ou à des périodes de formation sur le tas (ou les deux), dispensées par des professionnels compétents. Comme il existe un roulement élevé du personnel dans la plupart des camps de travail, en particulier en ce qui a trait au fonctionnement des installations de traitement des eaux usées, il faudrait offrir ces séances de formation au moins une ou deux fois par année.

Nous conclurons en disant qu'il est nécessaire de disposer de bons programmes de collecte et d'évaluation de données sur les installations de traitement des eaux usées dans l'Arctique canadien. Ce facteur est important aussi bien pour l'élaboration de lignes directrices appropriées sur les effluents que pour la conception d'installations rentables de traitement des eaux usées.

1.0 INTRODUCTION

1.1 SCOPE OF STUDY

Current sewage handling and disposal practices within marine environments north of the 60° latitude are quite variable and not predicated by a fixed policy or set of guidelines or regulations. For example, the sewage from coastal communities and petroleum exploration work camps is sometimes discharged with minimal treatment. In other cases, operators have voluntarily installed secondary treatment systems at work camps. In such cases, operators are expected to maintain and to operate these plants in an acceptable manner.

The first purpose of this current study is to provide a data base to assist in the clarification of key environmental issues related to the discharge of sewage effluents to Arctic marine environments. A second important purpose is to develop a knowledge base regarding various sewage treatment options under Arctic and High Arctic conditions.

1.2 TERMS OF REFERENCE

The specific terms of reference have been quoted directly from the statement of work for this project as follows:

"1. Collect, review, and summarize the present practices, policies and regulations pertaining to sewage treatment and disposal to inland and offshore water in Canada;

2. Collect, review/evaluate, and summarize the efficiency and effectiveness of sewage treatment systems (for use by up to 125 people) currently in use on inland and offshore waters in Canada, which could be applicable to offshore industrial activities in the north;

3. Collect, review/evaluate, and summarize the effectiveness of sewage treatment systems (for use by up to 250 people) currently in use on inland and offshore waters and shorebase facilities in Canada which could be applicable to shorebase camps and bases in the north;

4. Collect, review, and summarize the short-term and long-term environmental effects of discharging treated and untreated sewage into Arctic marine environments, with particular attention (but not limited) to: areas of recreational beaches; areas of commercial, domestic and native harvest fishing, and environmentally sensitive areas;

5. Make recommendations, based on the above information, regarding the short and long-term discharge of sewage to Arctic marine environments; and

6. Identify and provide information on the optimal primary and secondary treatment systems that will operate efficiently and effectively (including cost effectiveness) in the north on a seasonal and year round basis".

2.0 REGULATORY PRACTICES AND POLICIES

2.1 INTRODUCTION

The regulatory responsibilities for effluent quality criteria in the Northwest Territories and the Yukon lie primarily with Indian and Northern Affairs Canada and a number of other government agencies. The Arctic Waters Pollution Prevention Act and the Northern Inland Waters Act are the major enforcement tools in the Arctic.

Particular legislation which is relevant for the discharge of sewage effluents into the Arctic marine environment includes:

1. Arctic Waters Pollution Prevention Act and Regulations;
2. Northern Inland Waters Act and Regulations;
3. Canada Oil and Gas Production and Conservation Act and Drilling Regulations;
4. Public Health Ordinance;
5. Canada Water Act;
6. Guidelines for Canadian Recreational Water Quality.
7. Canada Shipping Act and Regulations

The following Sections review each of these in more detail. In addition, we have summarized the Great Lakes Sewage Pollution Prevention Regulations and have included current Alaska regulations in our discussion.

2.2 ARCTIC WATERS POLLUTION PREVENTION ACT AND REGULATIONS (AWPPA)

The AWPPA is the major piece of legislation under which waste discharge to Arctic marine waters is regulated. This Act covers the water quality management of coastal and marine areas in the Arctic north of 60° latitude. It provides for the development of regulations for "prescribing the type and

quantity of waste, if any, that may be deposited by any person or ship in the Arctic waters or in any place on the mainland or islands of the Arctic where such wastes may enter the Arctic waters. Waste is broadly defined in this Act as any substance or any waters containing a substance which, when added to water can be detrimental to humans, animals or plants.

The general provisions of the AWPPA for non-shipping activities are enforced by Indian and Northern Affairs Inspectors for all areas except Hudson Bay and Hudson Strait where the Act is administered by Energy, Mines and Resources. Regulations specific to pollution from ships are enforced by the Canadian Coast Guard. The Act and its Regulations apply to the waters adjacent to the mainland and islands of the Canadian Arctic extending seaward from the nearest Canadian land a distance of 100 nautical miles, except for special considerations where this zone overlaps with Greenland territorial waters.

2.3 NORTHERN INLAND WATERS ACT AND REGULATIONS (NIWA)

This Act covers the management of the fresh water resources in the Territories and is in accordance with the licencing recommendations of the Territorial Water Boards. The Northwest Territories Water Board and the Yukon Territory Water Board have been established under the Northern Inland Waters Act. The objectives of these boards are to provide for the conservation, development and utilization of the Water Resources of the Territories in an acceptable manner. These Boards have issued guidelines for the discharge of domestic waste into freshwater and marine environments. These guidelines which are drawn from, or act in conjunction with the various federal acts and standards are as follows:

1. Guidelines for Municipal Type Wastewater Discharges in the Northwest Territories 1981; and,
2. Guidelines for Municipal Wastewater Discharges in the Yukon Territory 1983.

The following is an excerpt from the Northwest Territories Guidelines as they pertain to marine discharges:

> "Wastewater with the specified characteristics must be discharged by outfalls which are designed according to the specifications given in Appendix A. In general, discharge of untreated wastewater to the open sea is permitted, if as a minimum, floatable materials are removed and the discharge is comminuted or macerated. The requirements for discharges to bays and fjords may be relaxed, depending on the findings of site-specific studies." (Section 2.1, p. 14)

Both the Yukon and Northwest Territories Guidelines have some flexibiity as illustrated by the following excerpt from the Yukon guidelines:

> "The Board will consider applications on a site-specific basis and may take a flexible approach to the application of these Guidelines, provided it is demonstrated that variations from them are acceptable." (Section 1.1, p. 3)

Effluent objectives for the Northwest Territories and the Yukon are summarized in Tables 2.1 and 2.2. Both Guidelines define the licensing requirements for shore-based communities and camps. They do not pertain to offshore vessels and artificial islands and drilling structures.

2.4 CANADA OIL AND GAS ACT AND DRILLING REGULATIONS

These regulations which are administered by COGLA, regulate drilling activity in the Arctic by means of Drilling Program Approval (DPA) and Authority To Drill A Well (ATDW) Licences. Sewage treatment requirements are regulated through the various environmental conditions and environmental operating conditions attached to these licences. These are recommended to COGLA by Indian Northern Affairs Canada through the Arctic Waters Advisory Committee, a body comprising various federal and territorial government agencies and native groups.

TABLE 2.1

EFFLUENT QUALITY FOR MUNICIPAL WASTEWATER DISCHARGE IN THE NORTHWEST TERRITORIES

Wastewater Flow Ratios[2] (Sewage Strength)	Parameters	Areas Marine Open Coast	Areas Bays and Fjords
LT or equal to 0.5 (high)	BOD, mg/l	600	360
	SS, mg/l	725	250
	pH	---	---
	Oil, grease	none visible	none visible
	P, mg/l	---	2.0
	Coliforms (MPN/100 ml)	See Note 3	
GT 0.5 LT 2.0 (normal)	BOD, mg/l	300	180
	SS, mg/l	360	125
	pH	---	---
	Oil, grease	none visible	none visible
	P, mg/l	---	2.0
	Coliforms (MPN/100 ml)	See Note 3	
LT or equal to 2.0 (low)	BOD, mg/l	150	90
	SS, mg/l	180	60
	pH	---	---
	Oil, grease	none visible	none visible
	P, mg/l	---	2.0
	Coliforms (MPN/100 ml)	See Note 3	

Notes:

1) Taken from Guidelines for Municipal Type Wastewater Discharges in the Northwest Territories, 1981

2) Flow ratio = (Actual Wastewater Flow)/(300 l/person/day)

3) Only in the case of a fishery or recreational use of water would bacteriological standards be of concern.

4) LT and GT denote "less than" and "greater than".

TABLE 2.2
RECEIVING QUALITY OBJECTIVES FOR MUNICIPAL EFFLUENT IN THE YUKON TERRITORY

Parameter	Objectives
Dissolved Oxygen	7mg/l (not to exceed 10% over background)
Residual chlorine	0.02 mg/l
Coliforms	200 MPN/100 ml
Settleable Solids	negligible increase
Floatable Solids	negligible increase
Oil and grease	1 mg/l
Organisms	no undesirable change in productivity
Metals	negligible increase

Notes:

1) Taken from Guidelines for Municipal Wastewater Discharges in the Yukon Territory

2) Water quality objectives are to ensure non-gradation of the receiving water

3) The parameters may not be applied in marine areas

4) The specified parameters are for the area outside of the initial mixing zone

5) Applicants may release an effluent which does not meet these criteria if it can be proven that no environmental damage is likely to occur

2.5 PUBLIC HEALTH ORDINANCE

The Public Health Ordinance covers the methods required to maintain a high quality of cleanliness for the prevention of disease. Methods and equipment required to obtain the health objectives are specified for work camps and for the discharge of municipal effluent.

Statements in this Ordinance relevant to this study are as follows:

> "No final disposal of effluent from a sewerage system shall be carried out in a manner that creates:
>
> a) a health hazard with respect to water supplies, swimming beaches or any body of water in the area . . ." (Section 7.1, Public Sewerage Systems Regulations)

2.6 CANADA WATER ACT

This Act encompasses the general philosophy and responsibilities for the proper management of the water resources in Canada. It defines the relationship between the federal and provincial agencies and refers to specific regulations or guidelines which may supercede the objectives contained in this Act. The only specific regulations in the Act are for the use of phosphate in detergents.

2.7 GUIDELINES FOR CANADIAN RECREATIONAL WATER QUALITY

The guidelines for recreational water use state that:

"a maximum geometric mean of not less than 5 samples taken over a 30-day period is set at 200 faecal coliforms/100 ml." (Section 3.1.3, p. 17)

2.8 CANADA SHIPPING ACT AND REGULATIONS

This Act covers the discharge of pollutants from ships operating in Canadian waters including all areas north of the 60th latitude. The dumping of garbage is not allowed anywhere within this area. The Governor in Council is responsible for stipulating the regulations concerning the discharge of liquid pollutants from ships. The discharge of wastewater from ships is not allowed in harbours and confined waters but is allowed in open waters.

2.9 OTHER LEGISLATION

There are several other Canadian legislative acts which would have to be considered if sewage were to be discharged into the marine waters of the Arctic. These Acts do not have specific references to water quality standards but do contain general standards which must be achieved.

2.9.1 Fisheries Act

This Act does not have specific effluent guidelines but does prevent the discharge or dumping of any material which may be deleterious or harmful to fish and fishing grounds. The discharge of sewage effluent would not be allowed if it was considered to be potentially harmful to local fishing grounds. (Section 33, Pollution of Waters and Injury to Fishing Grounds)

2.9.2 Ocean Dumping Control Act

This Act requires that permits be issued for the dumping of wastes from ships, platforms or aircraft in other than inland waters. The only time an ODCA permit would be required for sewage disposal is if a large bulk discharge of accumulated sewage sludge were to occur, or if sewage was stored on a barge for the express purpose of dumping at sea.

2.9.3 Migratory Birds Convention Act

A section in this Act states, "No person shall deposit or permit to be deposited ... any substance harmful to migratory birds in any water or any area frequented by migratory birds. (Section 35, Pollution)

2.9.4 Navigable Waters Protection Act

If outfalls or other types of sewage works are to be constructed to discharge sewage effluent, then the structure must be properly identified with the appropriate lights, markings and notices.

2.9.5 Territorial Lands Act, Public Lands Grants Act

These Acts cover special regulations or easements which may apply to particular groups or companies concerning the use of lands which are in the public domain. When companies wish to operate on Crown land, permits are issued to the companies. These permits require that in the case of offshore islands, the company must submit sewage treatment and disposal plans to INAC for approval prior to occupying the land. For onshore operations these permits address sewage disposal. The Inuvialuit Lands Administration also attaches special conditions to land access permits which define acceptable sewage management practices. Most camps are required to use holding tanks which are subsequently emptied and discharged to existing municipal treatment plants.

2.10 GREAT LAKES STANDARDS FOR VESSEL DISCHARGE

The most stringent standards for offshore discharges from vessels operating in Canadian waters are the Great Lakes Sewage Pollution Prevention Regulations under the Canadian Shipping Act as administered by the Federal Ministry of Transport. To be approved for use on vessels operating in the Great Lakes, sewage treatment systems must undergo rigorous land testing in an approved

testing establishment, and they must meet the following limits, based on average results:

TSS = 50 mg/l or less
BOD = 50 mg/l or less
Chlorine residual not less than 0.5 mg/l nor more than 1.0 mg/l after 30 minutes contact time, or alternatively,
Total Coliforms = 200/100 ml or less

The alternatives to treatment and discharge from vessels include incineration or retention in holding tanks and discharge to shore-based treatment facilities. The regulations also provide specifications for the design and construction of holding tanks and for the type of incinerators to be used.

2.11 ALASKA REGULATIONS

Under the U.S. Clean Water Act, the Environmental Protection Agency (EPA) is required to develop National Pollution Discharge Elimination System (NPDES) permits for waste discharges to the marine environment from offshore operations. Discharge standards are set on the basis of site specific assessments. Before issuing a permit, the EPA must determine that the proposed discharge will not result in unreasonable degradation of the marine environment.

Steinborn and Thiel (1985) reported that each of these permits has been a "Best Professional Judgement" permit; that is, the EPA has used its best professional judgement in developing effluent limitations. They reported that "unreasonable degradation of the marine environment" was defined as:

1. Significant adverse changes in ecosystems diversity, productivity, and stability of the biological community within the area of the discharge and surrounding biological communities;

2. Threat to human health through direct exposure to pollutants or through consumption of exposed aquatic organisms; or

3. Loss of aesthetic, recreational, scientific or economic values, which is unreasonable in relation to the benefit derived from the discharge.

Smokler and Byers (1985) reported that it was currently difficult to establish permit levels for marine discharges in the Beaufort region because of the complicating and relatively unresearched effects of shallow water, low ambient water temperature, low velocity currents, and seasonal solid ice cover in relation to dispersion requirements.

2.12 CURRENT REGULATORY PRACTICES AND POLICIES IN CANADIAN MARINE WATERS

As reported in Section 2.5, the effluent requirements for discharge to marine environment from shore-based facilities must be in accordance with licencing requirements set out under the NIWA. Minimum effluent standards under the Guidelines for the Northwest Territories and the Yukon were reported in Tables 2.1 and 2.2. These may be modified at a specific site upon recommendation of the Territorial Water Board. The AWPPA also provides the legislative vehicle for the control of waste discharges to Arctic marine waters but has characteristically only been applied to offshore rather than shore-based activities.

There currently are no specific regulations regarding the quality of effluents discharged from offshore facilities and marine vessels in the Arctic or in Atlantic and Pacific marine waters in Canada. Trider (1986) reported that current treatment practices for vessel sewagaes in Atlantic waters are restricted to comminuction only and discharge of raw sewage. The same was reported for Pacific marine waters (Schormann, 1986). In the case of both Atlantic and Pacific waters, this treatment is done purely on a voluntary basis by shipping companies.

Both the regulatory policies as well as the industry practices in the Arctic have been somewhat flexible. Edwards (1986) reported a short history of regulatory practices in the Canadian Arctic. Prior to 1978, secondary sewage treatment was generally the requirement for offshore facilities. The standard for drillships was modified downward in 1978/79 to require only primary treatment.

The first guidelines appeared in 1982. Although they did not set effluent quality limits, they called for regular sampling and analysis of specific pollutants. In the next year, the following limits were set on sewage effluents from artificial islands:

BOD less than 180 mg/l
TSS less than 125 mg/l
No visible oil and grease
pH of 6 to 9

Drillships were allowed to continue with only primary treatment.

Subsequent to 1983, these standards have been relaxed. The current policy is that operators must operate their waste treatment plants to the satisfaction of the Conservation Engineer and in accordance with good industry standards. Sampling of the effluent and analysis of BOD, suspended solids, oil and grease and pH is required at a frequency of not less than once monthly.

Current sewage treatment practices in the Arctic are somewhat variable. Most drillships discharge raw sewage directly following maceration. In other cases, such as the Gulf-owned drilling platforms Kulluk and Molikpaq and all but two of Dome's five drillships, full secondary treatment including disinfection is provided. Devenis (1986) reported that while the Arctic standards did not require the technology, Gulf's ships were constructed with these sewage treatment facilities in order that they would have the flexibility of operating anywhere in the world.

Sewages from artificial islands in the Beaufort region are generally afforded full secondary treatment prior to direct discharge to the marine environment. The sludges which are produced through biological treatment processes are also discharged to the marine environment. Further details of treatment processes are discussed in Section 3.

2.13 CONCLUSIONS

There are a considerable number of regulations pertinent to Arctic marine discharge of sewage effluents. However, the current legislation is generally vague in its application or not strictly applied at all. There is considerable division of responsibilities. The AWPPA which is the major piece of legislation intended to regulate water management of coastal and marine areas north of 60° is vague.

The previous policies regarding sewage treatment in the Arctic marine environment have fluctuated and have even been somewhat erratic. This probably reflects two situations:

1. The current shortage of good research results; and

2. The relatively low level of activity which currently characterizes oil and gas exploration activities.

There is a need to develop a consistent policy based on good research data. The requirement for these policies will become particularly important as exploration activities become superseded by more intensive oil and gas production in the Arctic.

3.0 SEWAGE TREATMENT PRACTICES

3.1 INTRODUCTION

Current sewage treatment practices in the Arctic and High Arctic are probably more variable than anywhere else in Canada. Treatment objectives range from no treatment at all except perhaps for coarse solids removal or maceration, to complete tertiary treatment for removal of residual BOD, suspended solids and coliforms. Even the sewage characteristics themselves are extremely variable. Raw effluents from "honey bag" sewage collection systems are usually of very high strength, those from construction and work camps are of medium to high strength, and sewages collected from communities using water bleeders for freeze protection are usually extremely dilute. This Section reviews briefly the wastewater characteristics including their variability in the Arctic and describes the most common methods of sewage treatment currently used in both shore-based and marine facilities.

By far the most common form of sewage handling in the Arctic has consisted simply of coarse solids screening or maceration followed by direct discharge to the receiving environment. In some cases, direct discharge may be preceded by settling of suspended solids in earthen basins or pits. This latter combination of processes is commonly referred to as primary treatment.

The next stage in sewage treatment involves further removal of suspended solids and reduction of the dissolved organics portion of the sewage through biological, physical and chemical processes. Typical processes would include lagoons, activated sludge reactors, fixed film biological reactors, and physical chemical treatment. These options, collectively referred to as secondary treatment processes, are described in detail in this Section. Also described are some additional options, not widely used at the present time but either proposed or tried on a small scale in Arctic applications. The objectives of all secondary treatment processes include BOD and suspended solids reductions of at least 85 to 90 percent.

Where residual suspended solids, BOD, coliforms or nutrients are of potential concern in the receiving environment, additional treatment beyond a secondary level may be required. Typical processes which have been used under these conditions include disinfection for coliform reduction and activated carbon adsorption for removal of residual suspended solids and BOD.

3.2 WASTEWATER CHARACTERISTICS

3.2.1 General

As stated previously, the focus of this Study is sanitary and domestic waste water. The characteristics of the wastewater, that is the quantity and quality, will depend on the type of community or facility being served and on the type of sewage collection system installed.

3.2.2 Wastewater Quantities

The total quantity of wastewater produced by a community or facility is generally close to the quantity of potable water consumed. Since underground sewage collection piping is normally insulated and sealed to maintain thermal protection, infiltration is not a concern in most northern systems.

The total quantity of wastewater produced from shore-based and offshore activities is governed primarily by the type of community or facility and the availability of water supply. For example, most trucked water supply systems consume less water than piped supply systems which have complete plumbing. Construction and drilling camps have relatively large per capita water use because they are fully equipped with plumbing systems and because they have high living standards such as elaborate food services. Table 3.1 activities illustrates the variation in per capita wastewater flows which occur in the Arctic.

TABLE 3.1
WASTEWATER QUANTITIES
(Smith, 1986)

Installation		Quantity (litres/capita · day)
1.	Permanent Military Base, 1000 population, conventional piped water and sewage	200 - 350
2.	Trucked water, conventional plumbing (average)	140
3.	Trucked water, low flush toilets (average)	90
4.	Water tank and honey bucket toilet, no plumbing (average)	1.5
5.	Same as 4. above but with central bathhouse (average)	15
6.	Construction camp	190 - 260

3.2.3 Wastewater Quality

The physical, chemical and biological characteristics of wastewater are dependent on the type of water supply and sewage collection system. Wastewaters in the Arctic have been classified into the following four categories:

1. undiluted,
2. moderately diluted,
3. conventionally diluted,
4. greatly diluted.

Undiluted wastewater is produced in areas where bucket toilets (honey buckets) are used.

Moderately diluted wastewaters are produced where water conservation is practised, or where holding tanks are installed. They are also characteristic of shore-based and offshore construction or drilling camps where food wastes and toilet wastes form a significant component of the wastewater.

Conventionally diluted wastewater is produced in communities which have piped water supply and sewage collection systems, but where water bleeding for freeze protection is not practised on a large scale.

Greatly diluted wastewater occurs where bleeding of water to the sewer system is widely practised.

In some applications, particularly on marine vessels, greywater may be collected and treated separately from blackwater. Greywater may be defined as the wastewater generated by water-using fixtures and applicances, excluding toilets and food wastes. Blackwater is defined as liquid and solid body waste and the carriage waters generated through toilet usage as well as food wastes. Seawater is often used as flushing water for blackwater systems on marine vessels. It has the effect of raising the total dissolved solids concentrations of blackwater. Table 3.2 summarizes wastewater characteristics from the various categories.

TABLE 3.2

CHARACTERISTICS OF BASIC WASTEWATER CATEGORIES

(Smith, 1986)[1]

Parameter	Units	Undiluted	Moderately Diluted	Conventional Diluted	Greatly Diluted	Greywater
BOD_5	mg/L	--	460 280 - 700	220 110 - 400	55 40 - 60	--
COD	mg/L	110,400 80,800 - 134,800	1000 700 - 1300	500 250 - 1000	--	(TOC) 210 40 - 900
Susp. Solids (NFR)	mg/L	78,200 66,000 - 85,000	490 370 - 820	220 100 - 350	50 20 - 150	290 40 - 2000
Total Nitrogen	mg/L as N	8100 7300 - 9500	--	40 20 - 90	(NH_3) 10. 6 - 30	(NH_3/N) 1.4 0 - 8
Phosphorus	mg/L as P	1200 1100 - 1400	--	8 4 - 15	3 2 - 6	9 4 - 200
Calculated Flow[2]	L/c/d	1.2 1.1 - 1.4	170 110 - 290	360 200 - 730	1500 1300 - 2000	310 50 - 2300

Note:

1) All values have been rounded off from published data.

2) Calculated based on 80 g BOD_5 per person per day and 90 g suspended solids (SS) per person per day (where applicable).

3.3 COMMONLY USED SEWAGE TREATMENT ALTERNATIVES

3.3.1 Introduction

The following Sections describe those secondary treatment alternatives most commonly used in the Arctic. Specific advantages and limitations for each are reviewed on the basis of documented evidence. Cost estimates have also been prepared.

3.3.2 Lagoons

3.3.2.1 General Description

Lagoons are currently used for sewage treatment at shorebase facilities. Three types are commonly found. The first includes deep anaerobic pits which are constructed with a relatively small surface area to depth ratio. This reduces the opportunity for oxygen transfer from the surface interface with the air and restricts the penetration of sunlight, thereby resulting in anaerobic (without oxygen) conditions for most of the pond's depth. Degradation of wastes occurs under the action of micro-organisms that thrive in these conditions. The opposite extreme occurs in aerobic ponds where the depth to surface area ratio is very small. This promotes the activity of aerobic micro-organisms which stabilize the wastes.

A third situation prevails with ponds having relatively large surface area and depth. Such ponds are called facultative stabilization ponds. In these ponds, aerobic conditions prevail at the surface while anaerobic conditions occur near the bottom. (Facultative organisms are those that can exist in either aerobic or anaerobic environments).

A modification of the aerobic lagoon also relies on the activity of aerobic micro-organisms, but the rate of transfer of oxygen to the sewage is increased by using mechanical aeration devices.

Pond systems generally have a large volumetric capacity. Sewage is retained for a sufficient period of time to allow natural settlement and treatment by the organisms to occur prior to release of the effluent to the environment.

The use of facultative lagoons has been common in northern areas. They offer the following advantages:

1. they have minimal operating and maintenance requirements;
2. mechanical breakdowns are eliminated;
3. they are able to handle wide fluctuations in hydraulic and organic loading;
4. they have no external energy requirements; and
5. the functional life of a lagoon can be expected to surpass that of a mechanical plant.

Despite their strengths, they have three major disadvantages:

1. land requirements are relatively high when compared to mechanical treatment processes;
2. the potential for malodours is relatively high, particularly during and immediately following spring break-up; and
3. effluent quality deteriorates during cold water and ice-covered discharge periods.

Aerated lagoons have been used in locations where land value or other constraints such as improved effluent quality requirements make them economical. Design normally follows conventional practice with adjustments for temperature, ice cover and sludge accumulation. Where aeration devices are used all year, subsurface diffusers are preferrable to mechanical surface aerators. Air line protection from freezing during shutdown periods is an important consideration.

The shallow-pond aerobic design referred to earlier is not suitable for most Arctic applications because these ponds freeze solid during the winter months.

3.3.2.2 Applications and Limitations

Smith and Finch (1983) reported there were 15 lagoon treatment systems in use in the Northwest Territories and eight in the Yukon. Lagoons represented 70 percent of the treatment facilities used in both territories at that time. Most of these were faculative lagoons.

The same authors evaluated lagoon performance in cold climate applications. They found that although the published literature included numerous reports on lagoon performance, a major problem was that most presented seasonal operating data only as discrete data points. It was therefore very difficult to establish representative mathematical performance relationships or even to draw conclusions regarding lagoon performance. The authors tabulated available data for 15 communities in the Northwest Territories and 5 in the Yukon. The results (Table 3.3) illustrate that performance data were very sparse.
The authors made the following general observations:

1. Summer performance of Arctic lagoons is similar to that of southern, warm weather facilities;

2. Winter performance deteriorates since ice and snow cover, combined with near freezing temperatures, reduce the operation of a lagoon to a sedimentation basin and there is an accompanying decline in performance for BOD, suspended solids, and fecal coliform removals; and

3. The most common problems cited were odours, water leakage through the berms, insects, lack of safety, erosion, sludge accumulation and failure to meet effluent standards during the winter months.

The authors concluded that there are no uniform criteria for reporting lagoon performance since effluent characteristics bear little relationship in the published literature to the influent raw wastewater. They noted that few comprehensive studies of existing cold climate lagoon systems have been carried out in North America.

TABLE 3.3

SUMMARY OF PRESENT LAGOON PERFORMANCE NORTH OF 60 (SMITH & FINCH, 1983)

Location	Latitude (approx.)	Population Total/Served	Collection System	Lagoon Type	No. Cells	Op. Mode	Discharge Mode	Retention Time (d)	Daily Org. Loading kg BOD	BOD Removal %	S.S. Removal %	Remarks
Baker Lake, NWT	64°18'N	1062/1062	tank/bag	fac.	2	series	cont.	1891				Natural lakes
Enterprise, NWT	60°15'N	40/40	tank	anaer.	1	--	cont.					Natural pond
Eskimo Pt., NWT	61°05'N	994/994	tank/bag	anaer.	1	--	cont.					Mod. pond
Ft. Franklin, NWT	65°11'N	545/545	tank/bag	anaer.	1	--	intermit.	180				Spring & fall discharge
Ft. McPherson, NWT	67°27'N	793/200	pipe/tank/bag	other	1	--	cont.					Natural lake
Ft. Norman, NWT	64°54'N	359/359	tank/bag	fac.	1	--	cont					
Ft. Providence, NWT	61°21'N	554/554	tank	anaer/fac	4	par/ser	intermit.	365				Spring discharge
Ft. Smith, NWT	60°00'N	2297/2297	pipe	anaer/fac	3	par/ser	cont.	90	24/ha	50-90	80-95	
Hay River, NWT	60°51'N	3129/3129	pipe	anaer	3	par/ser	cont.					
Inuvik, NWT	60°50'N	1647/1647	pipe	anaer	2	series	cont.					
Rae, NWT	62°50'N	1350/1350	bag	fac	1	--	none	long				Twin towns
Edzo, NWT	62°50'N		pipe	fac	2	par/ser	cont.	51				
Tuktoyaktuk, NWT	69°27'N	762/762	bag/tank	other	1	--	none	long				Natural lake
Yellowknife, NWT	62°28'N	9550/9140	pipe	fac		No information supplied						Natural lake
Faro, Y.T.		1800/1800	-	anaer/fac	-	-	-	-				
Haines Jct, Y.T.		450/350	-	anaer	-	-	-	-				
Teslin, Y.T.		300/150	-	anaer/fac	-	-	-	-				
Watson Lake, Y.T.		809/600		fac	2	series	intermit.			50		Discharge bimonthly
Whitehorse, Y.T.	63°43'N	16929/15200				No information supplied						
Crestview		/200		anaer/fac	--	--	--	--	--	--	--	
Porter Creek		/5000		anaer	4	ser	cont.	17	--	39	53	
Whitehorse		/10000	pipe	anaer	4	par/ser	cont.	20	$0.01/m^3$	41	60	

The Inuvik lagoon system, constructed in 1957, was the first lagoon in the Canadian Arctic to provide sewage treatment for a whole community. It is also the first northern lagoon in Canada to be monitored on an ongoing basis (Smith and Finch, 1983). Magditsch and Heinke (1986) recently reviewed its operation following its upgrading from a single-celled to a three-celled system.

The authors concluded the following:

1. When the total system was considered, BOD reduction was 88 percent in summer and 55 percent in winter; there was no organic removal in the secondary cell, probably because organic removal in winter is a function of physical settling in the primary cells rather than bacterial action;

2. Suspended solids removal was reported to be lower in winter than in summer because of the production of algae during the summer months; suspended solids levels were still below the 30 mg/l guideline even in summer;

3. Total fecal coliform reductions in the primary cell were fairly constant throughout the year; the results were attributed to sedimentation; and

4. Coliform reductions in the secondary cell were almost nil during the winter.

Esvelt et al. (1983) reported a theoretical design procedure for a facultative lagoon system for Barrow, Alaska. The central component of their model was the fundamental equation for photosynthetic oxygen production as originally developed by Oswald (1960). They used this as a basis for setting an allowable design rate on a facultative sewage lagoon in an Arctic or subarctic environment and for predicting when a winter season accumulated oxygen deficit may be over come during the summer season. Their modelling results indicated that a facultative sewage lagoon at Barrow must be limited to a loading of about 13 kg

of BOD/ha · day (12 lb/acre · day) in order to allow complete reduction of the oxygen deficit with a margin of safety of about 60 days in a normal year. No actual operating data were available to provide a comparison with model results.

Panarctic's main base at Rae Point uses lagoon treatment to polish the effluent from a mechanical aeration system (INAC, 1986). The effluent is then discharged to a creek bed which is dry for considerable periods of time. Sewage from Dome's base camp at Tuktoyaktuk is trucked to a municipal lagoon while the sewage from Esso's base camp at Tuk is pretreated on-site and then either discharged directly to Tuk Harbour or pumped to the municipal lagoon. No design or operating data were available for any of these facilities.

3.3.2.3 Design Criteria

Anaerobic and facultative lagoons are currently used in the Arctic for sewage treatment from shore-based communities. They are relatively simple to construct and have low operating requirements. They are not suited to offshore bases because of land areas constraints.

The important factors in evaluating the suitability of lagoons for a particular shore-based site include the following (Smith and Finch, 1983):

1. geotechnical conditions,
2. impact of the impoundment on the existing soil thermal regime,
3. impact of the lagoon on the hydrology of the area,
4. site access for construction and maintenance, and
5. access to the effluent receiving environment.

The same authors stressed the importance of detailed knowledge of subsurface soil conditions in order to understand initial thermal conditions and the response of the soil thermal regime to the facility over time. They also stressed the importance of good construction techniques, both in permafrost and non-permafrost regions in order to ensure the long term physical integrity of the lagoon basin.

The four basic approaches used for the design of sewage lagoons include:

1. retention time,
2. organic loading,
3. empirical models, and
4. analytical models.

Smith and Finch (1983) reported on each of these and concluded that for northern lagoons, the retention time criterion is the best, particularly since little stabilization occurs over the winter months. McKinney (1982) suggested a retention time of 120 to 150 days for lagoons operated in cold regions. Dawson and Grainge (1969) recommended 180 to 365 days retention for Arctic lagoons.

Because little treatment, except sedimentation, occurs during the winter months, Smith and Finch (1983) suggested that lagoon systems should be sized to povided annual discharge in the autumn. Organic and micro-organism removals are at optimum levels during the summer months. They suggested:

1. That the timing of discharge should account for fall turnover and algae die-off; and
2. That detailed discharge procedures should be included in the design.

While there is no current consensus on the optimum number of cells for a lagoon, it is readily apparent that more than one-cell is preferred. Finney and Middlebrooks (1980) compared the performance of three-celled lagoons with a seven-celled lagoon in a cold region. Over the period of the study, the latter was found to perform the best. Depending on the size of facility or community being serviced, a two or three-cell facility is probably desirable for populations of 250 or less.

3.3.2.4 Conclusions on Lagoon Treatment

While lagoons are frequently used to provide sewage treatment in the Arctic, there are few data available on which to base performance. Certain conclusions may be drawn, however, relative to this study:

1. Because of land area requirements, they are suitable only for shore-based facilities,

2. Studies to evaluate the applicability of lagoons for a particular site must emphasize the presence or absence of permafrost, the potential impact of lagoon structures on the soil, impacts on the area hydrology and available access not only for construction but also for regular maintenance.

3. Lagoons should be designed with more than one-cell preferrably three or more, and they should provide long retention time in the range of 365 days. This latter criterion is particularly important where coliforms are a concern for the receiving environment.

3.3.3 Activated Sludge Processes

3.3.3.1 General Description

While lagoon treatment systems operate in earthen basins and rely on nature to provide the desired treatment, the remaining sewage treatment options discussed in this report operate as controlled processes utilizing mechanical equipment. Treatment occurs through biological, physical, and chemical processes. For the size of facility covered by this study (250 persons or less), these plants are supplied as pre-packaged units which are simply shipped to the site and installed.

The first category of mechanical treatment processes used is the activated sludge process. "Activated sludge" is formed by mechanically aerating a biologically degradable sewage for a sufficiently long period of time to form a concentration of settleable solids. The settleable solids are activated masses of

micro-organisms, commonly referred to as "activated sludge." The types of activated sludge systems currently in use include conventional activated sludge, oxygen activated sludge, contact stabilization, extended aeration and oxidation ditches.

The conventional activated sludge process incorporates an aeration tank with four to eight hours capacity. The aeration process is preceded by screening or comminution. The aeration tankage and aeration equipment and controls constitute the major portion of the plant. A schematic flow diagram of the conventional activated sludge process is illustrated in Figure 3.1.

The oxygen-activated sludge process is similar to the conventional system but oxygen is used instead of air. The use of oxygen increases the bacterial activity and results in decreased sludge volume and reduced aeration tank volume. Neither the conventional or oxygen-activated sludge processes are sold as package plants. Because of greater operational requirements they are more appropriately used in large communities.

In the activated sludge process, the removal of colloidal and dissolved organisms occurs in two stages. In the first, called adsorptive phase, these organics are adsorbed on the activated sludge particles. This generally occurs in the first 20 to 40 minutes after raw sewage is introduced into the aeration tank. In the second stage, oxidation occurs and the adsorbed organisms are metabolically assimilated by the micro-organisms in the activated sludge.

In a contact stabilization system, these two stages occur in different tanks rather than in a single tank as with the conventional activated sludge process. Firstly, the settled raw sewage is mixed with activated sludge and aerated in a contact tank for 30 to 90 minutes. During this time, the fine suspended, colloidal and dissolved organics are adsorbed by the activated sludge. This activated sludge with the adsorbed pollutants is then separated from the treated effluent in a clarifier and aerated for three to six hours in a second aeration tank. The schematic of a typical contact stablization package plant is illustrated in Figure 3.2.

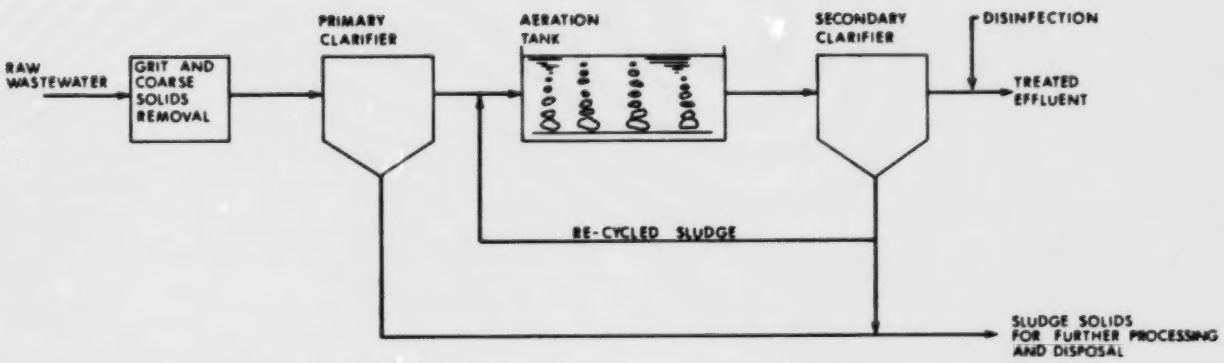


Figure 3.1

SCHEMATIC FLOW DIAGRAM OF THE CONVENTIONAL ACTIVATED SLUDGE PROCESS

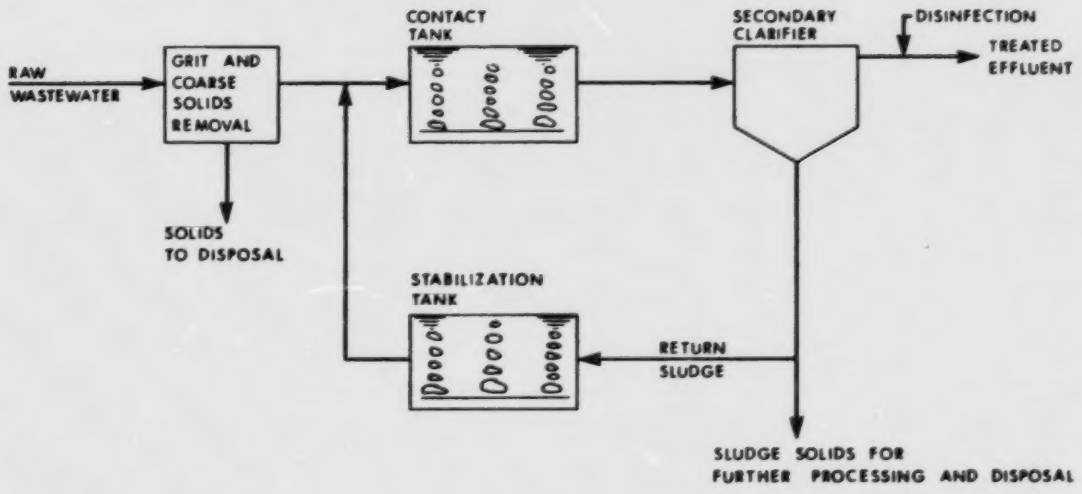


Figure 3.2

SCHEMATIC FLOW DIAGRAM OF CONTACT STABILIZATION PROCESS

The extended aeration process is similar to the conventional activated sludge process except that the hydraulic retention time in the aeration tank is in the range of 24 hours rather than the four to eight hours for the conventional process. Because of this large aeration basin capacity, the process is more capable of handling fluctuations in hydraulic loading. The quantities of sludge produced for disposal are relatively low. The primary clarifier is omitted from the process to simplify the sludge handling processes.

Because of its ability to withstand load variations, its relative simplicity, and its tendency to produce relatively small sludge quantities, the extended aeration process has been used quite extensively in small treatment plants. It is, in fact, the most popular package plant process being marketed today. Figure 3.3 illustrates the process schematic of a typical extended aeration treatment system.

The oxidation ditch is a variation of the extended aeration process in which the aeration tank consists of a channel approximately two to three metres wide and in a race-track configuration. The activated sludge is kept in suspension with the use of a horizontal or vertical shaft mechanical aerator which rotates and propels the liquid around the channel with a horizontal velocity of 0.5 to 1.0 metres per second. Air is entrained by the mechanical agitation provided by the rotor. Figure 3.4 illustrates the process schematic of a typical oxidation ditch treatment system.

3.3.3.2 Applications and Limitations

Smith (1986) described the important factors in selecting and utilizing one of the activated sludge treatment options. He summarized available design data by stating that basic process design criteria for the Arctic do not differ from those of conventional temperate-zone practice. He provided some practical guidelines in order to overcome some of the harsh climatic influences:

1. Significant ice formation must be avoided in the aeration compartments of these systems;

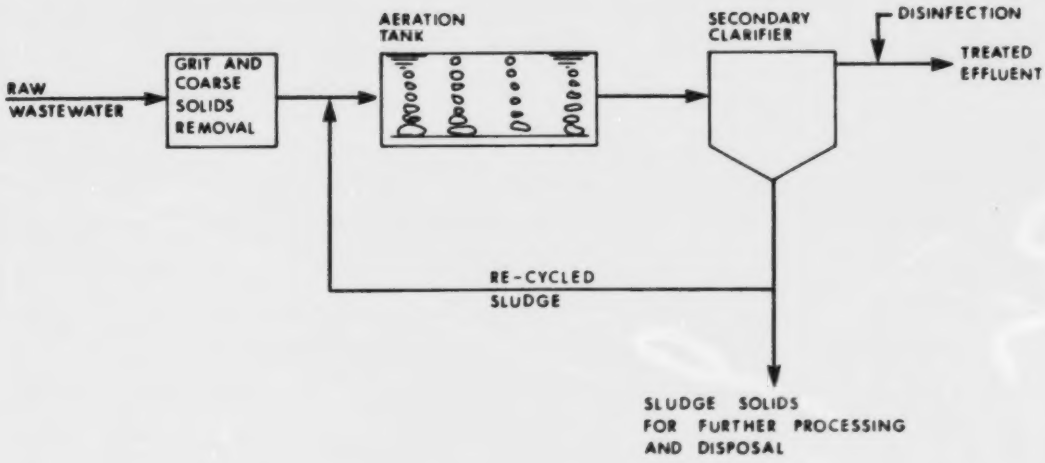


Figure 3.3

SCHEMATIC FLOW DIAGRAM OF THE EXTENDED AERATION PROCESS

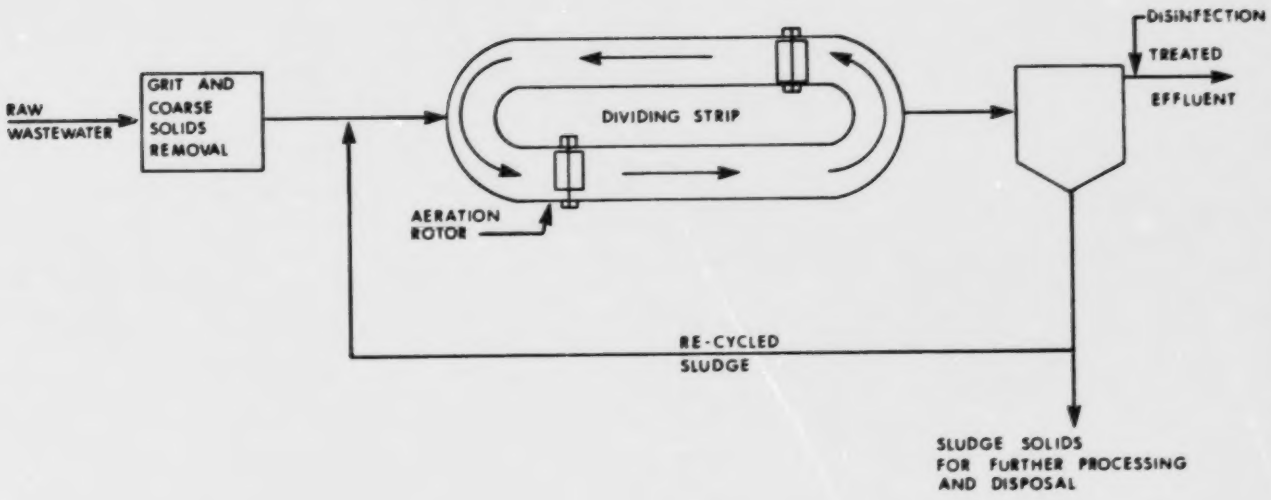


Figure 3.4

SCHEMATIC FLOW DIAGRAM OF THE OXIDATION DITCH PROCESS

2. Settling tanks and clarifiers should be protected to reduce heat loss and inhibit formation of density currents;

3. It is not normally necessary to provide a continuously heated building to maintain treatment efficiency since process performance can be maintained at sewage temperatures as low as 1°C; freeze protection in the form of tank covers, tank burial, wind breaks or unheated shelters are normally sufficient to maintain good performance; and

4. Although oxidation ditches have been used successfully in subarctic Alaska, modifications to their configuration are required to reduce heat losses; suggested modifications included vertical side walls and a thin vertical centre island, protective housing over the rotors, and enclosed clarifiers.

The same author noted that the design of the units for work camp situations should make allowance for intermittent loadings and wide fluctuations in population. Equalization tanks were recommended for flow damping. Where large population changes are anticipated, the use of multiple units operating in parallel was suggested.

Reed et al. (1985) have provided a thorough review of problems associated with the cold weather operation of mechanical treatment plants. They grouped cold weather operational problems into four main categories:

1. Ice formation and freezing in process components;
2. Viscosity changes in the wastewater and in lubricants in mechanical equipment;
3. Reaction rate change in physical, chemical and biological processes; and
4. Snow and ice accumulation on structures, control equipment, roads and walls.

The first of these was reported to be the most common.

While the same document was intended primarily to be a practical design and operating tool, it is important to note here that it also includes summaries of typical low temperature problems for preliminary treatment equipment, clarifiers, activated sludge processes, and sludge handling and disposal systems. Accompanying each of these reported problems are some practical suggestions to overcome these constraints. The authors concluded that while cold weather can seriously affect operation and performance of conventional sewage treatment processes including activated sludge systems, most of these problems can be eliminated or at least reduced to a tolerable level.

Miko et al (1983) reported performance data from a high purity oxygen activated sludge system at Fairbanks, Alaska. While the facility was designed to treat sewage from a population of 43,500 and is therefore beyond the size range to be covered by this study, it provides some observations relevant to this study:

1. Operator skill requirements for the plant were considered to be high; the operator certification program in the State of Alaska was relatively ineffective in preparing suitably skilled staff to operate the plant;

2. The encapsulation of the entire treatment facility because of its Arctic location resulted in a major corrosion problem because of high levels of oxygen, chlorides, sulphides and moisture in the building atmosphere;

3. Shock loadings from the discharge of septic tank sludge to the treatment system resulted in process upsets.

The authors monitored the performance of the plant for a one year period approximately six years after the plant had been commissioned. During that one year period, BOD and suspended solids removals averaged 72 percent and 85 percent respectively. No coliform data were reported.

By far, the most commonly used activated sludge system for communities of 250 persons or less is the extended aeration system. The process was illustrated earlier in Figure 3.3. Extended aeration package plants are usually constructed

of reinforced steel plate and consist of an aeration tank and hopper clarifier. Incoming raw sewage is screened or macerated before entering the aeration tank where it undergoes aerobic decomposition with the aid of aeration from compressors or blowers. Sludge is removed from the clarifier and returned to the aeration tank by airlift pumps or mechanical pumps. Provisions are usually included for periodic sludge wasting and for effluent chlorination.

Given and Smith (1977) provided an extensive evaluation of these systems in both Arctic and subarctic applications. A survey was made of 73 extended aeration package plants which ranged in size from 9.5 m^3/day to 3500 m^3/day (2,100 to 770,000 gal/day). Of the total, 42 of these plants were identified as "northern" (north of the $0^{\circ}C$ mean annual isotherm) while the remaining 32 were "non-northern" plants.

While the specific details of the survey are not contained in this report, the authors provided some important observations relevant to this study. Plant performance data from the survey are summarized in Table 3.4. They illustrate that while these plants are normally expected to provide removals of BOD, COD and TSS in the range of 80 to 90 percent or more, the majority of plants surveyed operated significantly below those expectations.

In order to understand the causes for poor plant performance, the authors documented all problems observed. Three problem areas more common to northern plants were identified as follows:

1. freezing problems with exposed oxidation ditches and associated detrimental effects on mixing and equipment;

2. lack of air circulation in encapsulated plants contributing to freezing problems with components located at lower levels; and

3. flooding of facilities due to slug discharge, system failures and lack of a back-up system.

TABLE 3.4

PLANT PERFORMANCE DATA FROM NORTHERN AND NON-NORTHERN PLANTS
(FROM GIVEN AND SMITH, 1977)

Parameter	Location	Influent (mg/l)		Effluent (mg/l)		Percentage Removal	
		Mean	Range	Mean	Range	Mean	Range
BOD_5	Northern	289	42-1900	118	12-670	56	0-96
	Non-Northern	156	2-500	49	2-215	60	0-98
COD	Northern	722	114-2830	518	53-3700	51	0-85
	Non-Northern	405	18-945	209	22-656	47	0-96
TSS	Northern	358	24-1550	201	14-820	58	0-94
	Non-Northern	242	3-1600	127	6-480	44	0-97

They reported that the generally poor performances of the northern extended aeration plants were related to both poor design and inadequate operation. The most significant design problems were associated with plant undersizing. This resulted in organic and hydraulic overloading. The most significant operator-related problems were failure to scrape hopper-type clarifiers, failure to maintain sludge returns operative, and insufficient operational time for blowers. They also noted that a common design oversight with most of the plants investigated was a lack of sludge wastage facilities.

The operation of mechanical sewage treatment plants by unskilled operators is a difficult problem to overcome, particularly in isolated northern work camps and Arctic communities. Clark et al. (1971) reported that many plants serving construction camps in Alaska exhibited poor performance because they did not receive qualified operator attention. In discussing extended aeration plants in Alaska, Coutts (1972) stated that, "If there are no plans to provide for a trained operator at each new plant, then it is a waste of money to buy or build the plant." In commenting on the shortage of skilled and conscientious operators for many of these plants, Given and Smith (1977) stated that "unless provisions in the design can be made (such as polishing lagoons and positive sludge return), or effective operator training programs are commenced, then this treatment alternative appears doomed to extinction".

As a final comment, Given and Smith (1977) suggested that the poor performance of northern plants was related more towards their degree of isolation than towards the harsh environment in which they are located. Firstly, isolation may lead to lack of interest by both administrators and operators. Secondly, breakdown of equipment components often leads to long delays before repair parts or replacements are ordered, shipped and installed. There is currently a shortage of well-qualified operators even for large population centres. Therefore, the current salaries of skilled operators are difficult to justify for small treatment plants and those operators themselves are usually unwilling to relinquish the challenge of working in a larger plant environment while enjoying the comforts and conveniences of urban life.

Pollen (1985) reported the successful use of extended aeration plants at petroleum production facilities in the Prudhoe Bay area of Alaska. Important design features of these package plants included:

1. adequate surge tankage upstream of aeration basins for flow control;
2. the incorporation of aerobic digesters for processing of excess sludges;
3. proper sizing of aeration basins;
4. sufficient air supply in the aeration basins; and
5. complete encapsulation of all equipment.

An operations plan was developed for the Prudhoe Bay area through the combined effort of plant operators. A contract monitoring laboratory was engaged to monitor plant performance and interpret test results. A training program is presented to the operators twice yearly to maintain and improve operator proficiency. The author reported that a recent survey of 19 extended aeration plants in the Prudhoe Bay area showed average removals of 96 percent each for BOD and suspended solids.

Operating data for extended aeration plants at offshore facilities in the Canadian Arctic are relatively sparse. Gulf reported the use of two separate extended aeration plants on their drilling platforms Kulluk and Molikpaq. Devenis (1986) reported that the treatment plants in both cases consisted of an aerated holding tank or equalization basin followed by the aeration tank, clarifier, and disinfection system. On the Molikpaq, both the greywater and blackwater were combined and treated. Numerous operating problems were encountered because of surge loadings particularly during showering and because of excessive grease loading from kitchen wastes. The electrocatalytic disinfection system was also reported to be a problem.

The same source reported that on the Kulluk, only the blackwater was treated while the ship's greywater was discharged directly to the ocean. Its operation was apparently more consistent and satisfactory.

Data supplied by INAC (1986) indicate that the effluent results from both plants were quite erratic. For the period from October 1983 to November 1985, the effluent quality from the Kulluk varied as follows:

1. BOD ranged from 140 to 3300 mg/L.
2. TSS ranged from 100 to 4280 mg/L.
3. Oil and grease ranged from 6 to 7410 mg/L.

For the period of December 1985 to May 1986 effluent results from the Molikpaq varied as follows:

1. BOD ranged from 33 to 210 mg/L.
2. TSS ranged from 50 to 1010 mg/L.
3. Oil and grease from 50 to 1010 mg/L.

The results indicate that in both cases, the treatment plants were rather erratic in their removal efficiencies and in many cases, the effluents discharged still had relatively high levels of BOD and TSS. The results should be reviewed cautiously, however, since they represent only a limited number of grab samples.

Panarctic has operated an extended aeration plant at its Rae Point base camp. Dales (1986) reported that the plant was installed in 1973 and has continued to operate until April of this year when the camp was vacated. Effluent from the plant is discharged to a sewage lagoon which is discharged once annually (during spring) to an adjacent creek. Sludges from the plant are discharged to waste oil pits for open pit burning.

Dales (1986) also supplied some operating results for the plant which are illustrated in Table 3.5. Grab samples were collected in both cases. The results indicate that on both occasions, the plant appeared to be providing relatively high removal rates.

Pessah (1986) indicated that Dome has operated four extended aeration plants on drillships in the Beaufort. In all cases, only the blackwater was treated.

Greywater was discharged directly to the sea. Mr. Pessah reported that the use of seawater for toilet flushing did not have any adverse impact on the treatment system. No plant operating data were available for this report.

TABLE 3.5
OPERATING RESULTS FOR PANARCTIC'S
RAE POINT EXTENDED AERATION PLANT
May and December, 1985

	May, 1985		December, 1985	
Parameter	**Influent**	**Effluent**	**Influent**	**Effluent**
pH	7.1	8.6	6.4	6.3
BOD (mg/L)	1676	30	780	55
TSS (mg/L)	4190	136	1370	355
Total Coliforms (MPN/100 ml)	LT 2400	nil	2400+	nil
Oil and Grease	30	11	58	LT 10

Schormann (1986) reported that most of the shipboard sewage treatment systems being used on Great Lakes vessels are extended aeration plants. He indicated that there were no operating data or reports available to characterize their performance.

Townshend (1977) compiled a summary report on the demonstration of the CABOS wastewater treatment system for vessels on the Great Lakes. This package plant was developed by the Ontario Research Foundation. It consists of an aerated equalization basin, activated sludge aeration basin, clarifier filter, media and an ozonation columm. Test results from three two week operating periods in 1975 indicate that average raw sewage BOD values for each time period varied from 690 to 1160 mg/L and TSS average concentration varied from 620 to 830 mg/L. Average effluent BOD concentration varied from 13 to 25 mg/L and a TSS average concentration varied from 5 to 13 mg/L. This

represents a very high treatment efficiency and it demonstrated the plant's capability to meet the requirements of the Great Lakes regulations.

3.3.4 Fixed Film Systems

3.3.4.1 General Description

In activated sludge systems, the micro-organisms are kept in suspension in the aeration tank in order to keep them in close contact with their food source - the organics present in the sewage. In fixed-film systems, the micro-organisms form a thin layer (5 to 10 mm thick) which is attached to an inert media such as rocks, plastic balls or discs, or wooden lathes.

By trickling a thin layer of sewage over this film, the attached micro-organisms are brought into close contact with the dissolved and suspended organic matter. At the same time, oxygen passes through this thin liquid layer, thereby maintaining aerobic conditions for the micro-organisms. The oxygen is supplied by natural ventilation or by mechanical or diffused aeration.

Fixed film reactors are normally constructed as packed towers or as rotating plates. Common fixed-film treatment processes which are marketed as package plants include trickling filters and rotating biological contactors (RBC).

Trickling filters basically consist of rocks or other material over which the sewage slowly trickles. If installed in the north, this type of system would have to be enclosed in a heated building. To date, there are no reported package plants in the Arctic which utilize the trickling filter concept.

Like the trickling filter, the RBC utilizes a biological film of micro-organisms to remove suspended and dissolved organics from sewage. The media to which the growth is attached consists of a series of circular plastic discs which are stacked horizontally on a shaft to form a cylinder. A schematic flow diagram of an RBC package plant is illustrated in Figure 3.5.

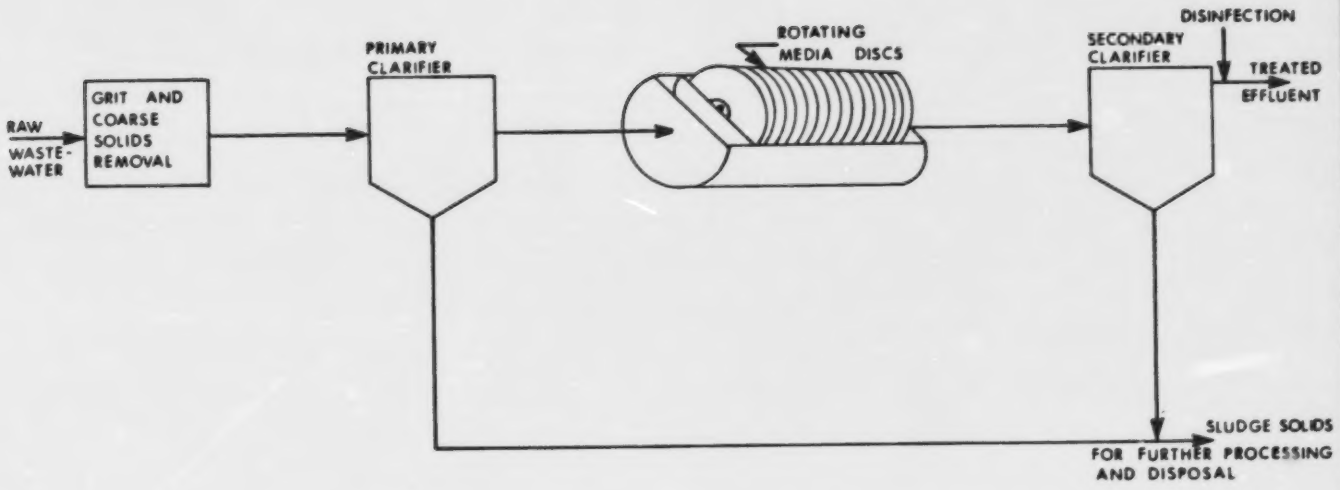


Figure 3.5

SCHEMATIC FLOW DIAGRAM OF THE ROTATING BIOLOGICAL CONTACTOR PROCESS

The discs are slowly rotated in a tank which contains the sewage to be treated. The micro-organisms attached to the disc adsorb the organic matter on the submerged portion of each rotation. During the exposed portion, the micro-organisms absorb oxygen from the atmosphere for their metabolism. This alternating cycle of submergence followed by atmospheric exposure distinguishes the RBC process from other fixed film systems.

As with all biological treatment processes, a sludge consisting of biological solids from the treatment process and inert suspended solids originally present in the raw sewage is also produced by RBC plants. The biological film which grows on the media is removed by continuous shearing forces as the unit rotates through the liquid. Solids are removed from the treated effluent with the use of hopper bottomed clarifiers, as previously reported for extended aeration package plants.

3.3.4.2 Applications and Limitations

Froese and Heuchert (1984) reported that at the time of their report, there were approximately 25 RBC package treatment plants in the Arctic regions of Canada, the United States and the U.S.S.R. They claimed that the plants offered some advantages which were particularly important in Arctic environments:

1. the system was very compact and could readily be installed in standard camp modules;

2. operation of the plants was very simple, particularly since sludge recycle was not required to control the efficiency of the biological treatment process;

3. the plants were relatively insensitive to hydraulic or organic upsets or to the introduction of slug loadings of chemicals such as bleach which are toxic to microbial growth.

They outlined the important components of RBC package plants used for work camps in the Arctic:

1. An aerated equalization basin sized to accommodate 50 percent of the daily flow during three peak periods each day;

2. An RBC media unit sized to treat a raw waste having soluble BOD and suspended solids concentrations of 300 and 500 mg/l respectively and at a temperature of 13°C;

3. Secondary clarifiers which are necessarily shallow (one metre) because of the need to house them in standard trailers which are Hercules-transportable, but have overdesigned surface areas sized to accommodate peak flows which are 2.5 times the average daily flow;

4. Frequent sludge withdrawal from the clarifiers with the use of positive displacement pumps; and

5. Treatment of the sludges in an aerobic digester sized to provide a sludge retention time of 15 days and a sludge concentration of 1.5 percent.

The authors reported that when these plants were operating under the types of conditions mentioned earlier, they consistently produced effluent BOD and TSS values less than 30 mg/l. Where experienced operators were responsible for running these plants, BOD and TSS values were often less than 10 mg/l.

PETWA (1986) supplied monitoring results from two separate RBC plants operating at oil and gas exploration islands in the Canadian Beaufort region. The results are summarized in Table 3.6. Grab samples were collected once weekly from both sites for the period 11 January to 28 February 1984. The average values in Table 3.6 were derived from eight sample results from each site. The results indicate that the plants were providing a relatively high quality effluent.

INAC (1986) supplied data from two grab samples collected from an RBC plant operating at Esso's Nipterk drilling site in the Beaufort Sea and one grab sample from an RBC plant at Esso's Adgo site in the Beaufort. The results (Table 3.7) illustrate that the two samples collected from the Nipterk site showed good

TABLE 3.6
PLANT PERFORMANCE DATA (PETWA, 1986)
AVERAGE CONCENTRATIONS

Parameter	Site 1		Site 2	
	Influent	Effluent	Influent	Effluent
pH	7.5	7.6	8.3	7.6
BOD (mg/L)	647	20	364	17
TSS (mg/L)	432	16	274	20
Total Coliforms (MPN/100 ml)	GT 240,000	Nil	GT 240,000	Nil
Fecal Coliforms (MPN/100 ml)	GT 240,000	Nil	GT 240,000	Nil

effluent quality. The Adgo sample shows a relatively poor effluent quality. They show high oil and grease values, probably from kitchen wastes. Excessive oil and grease will adversely affect treatment performance. No raw wastewater quality data were recorded. The effluents at both sites were discharged directly to the sea. Chevron used an RBC package plant at a drilling camp on Ellice Island (McCrae, 1986). No operating data were available for the plant. Treated effluent was discharged to the sea ice surface during the winter.

Dome Petroleum (Pessah, 1986) supplied us with operating data from an RBC plant operating at its McKinley Bay site. Mr. Pessah reported that the plant had operated for several months in 1983, and about one month in 1984 and not at all since then. The design criteria originally used to size the treatment plant for the 100-man camp were similar to those reported earlier in the Froese and Heuchert (1984) reference. The plant was sized hydraulically for an average daily flow of 29,500 litres (6500 Igal/day).

TABLE 3.7
GRAB SAMPLES FROM ESSO'S NIPTERK AND ADGO RBC TREATMENT PLANTS

Site Location	Sampling Date	BOD_5	SS	Oil & Grease
Nipterk	23 April/85	29	16	2
	17 June/85	18	7	2
Adgo	13 November/85	99	115	62

During 1983 operation, grab samples of the effluent were collected on a weekly basis from 19 July to 29 September. The average and maximum and minimum values are reported in Table 3.8. The results indicate that the plant was not able to achieve a high quality effluent. Since no raw wastewater data were available, it was not possible to evaluate treatment efficiency. Mr. Pessah indicated that the raw wastewater was considerably stronger than expected.

It is apparent that the plant may have been organically overloaded and not able to achieve a satisfactory effluent quality. Inability of the plant to provide full performance may also be due to the time factor. All biological treatment processes require a certain period of time for start-up to establish population of microorganisms. A minimum of one month is normally required for most activated sludge and attached growth systems. Even longer periods of time may be required for certain high-strength wastewaters.

Given (1984) reported the results of a pilot study conducted in Whitehorse, Yukon to investigate the treatability of dilute, cold wastewater with an RBC. While such a wastewater may not be representative of a typical Arctic work camp, it may be characteristic of a small community of individual dwellings with a piped water system and which practices water bleeding for utility freeze protection. The results indicated that BOD removal efficiency decreased as raw wastewater strength decreased. The process was capable of providing 85 percent removal of BOD and TSS from a wastewater having a total BOD less than 50 mg/l and

TABLE 3.8

SUMMARY OF McKINLEY BAY EFFLUENT ANALYSIS

(PESSAH, 1986)

Parameter	Average Concentration (mg/L)	Maximum Concentration Recorded	Minimum Concentration Recorded
BOD (mg/L)	210	280	117
COD (mg/L)	580	1120	450
TSS (mg/L)1	850	5100	85
Total Phosphorus (mg/L as P)	31	71	13
Ammonia (mg/L as N)	6.4	9.7	5.2
Oil & Grease (mg/L)2	45	307	10
Feacal Coliforms (No./100 ml)	36 x 106	95 x 106	5.4 x 106

Notes:

1. All TSS values were in the range of 100 mg/L except for two samples which were 5100 and 3350 mg/L.

2. All Oil & Grease values were in the range of 10-20 mg/L except for one sample at 307 mg/L.

suspended solids less than 40 mg/L at temperatures below 8°C. Very low organic loading rates were required, however, to achieve this treatment efficiency. The author concluded that manufacturers' design curves might not be applicable for these dilute wastewaters since they might lead to RBC undersizing. He also suggested that water bleeding should be minimized in RBC applications.

Forgie (1984) used pilot studies to evaluate the performance efficiency of the RBC process at temperatures below 10°C while treating medium strength wastewater (BOD of 380 to 490 mg/l and SS of 85 to 240 mg/l). The results indicated that over the range of 5°C to 15°C, the loss of efficiency was relatively minor but at temperatures below 5°C, loss of efficiency became more

severe, although BOD removal still remained in the 62 to 91 percent range even at a temperature of 1°C.

Schormann (1986) reported that some trickling filter plants were being used on Greak Lakes marine vessels. No operating reports or records were available. The plants were able, however, to satisfy the land tests required under the Great Lakes Regulations and they have been able to achieve the effluent limits required.

3.3.5 Physical - Chemical Systems

Package plants which are designated as physical-chemical systems do not employ the use of micro-organisms to accomplish pollutant removal. Instead, they use chemicals which form precipitates when added to the sewage. These chemicals also agglomerate the precipitates and other fine suspended solids into larger particles which can be removed by settling in a clarifier.

The flow diagram for a typical commercial physical-chemical treatment system is illustrated in Figure 3.6. Raw sewage is passed through large screens to remove coarse solids or through a comminutor to chop them. The heavy suspended solids or grit are then settled prior to the addition of chemical coagulants. The larger and heavier agglomerated particles formed following the addition of alum, lime or ferric chloride are settled as sludge in a clarifier. Following clarification, the effluent is usually passed through a fine filter composed of activated carbon particles whose function is the removal of dissolved organics.

The major reported advantages of physical-chemical plants are the following (Smith, 1986; Grainge et al, 1973):

1. relatively compact;

2. minimum site impact during construction and restoration;

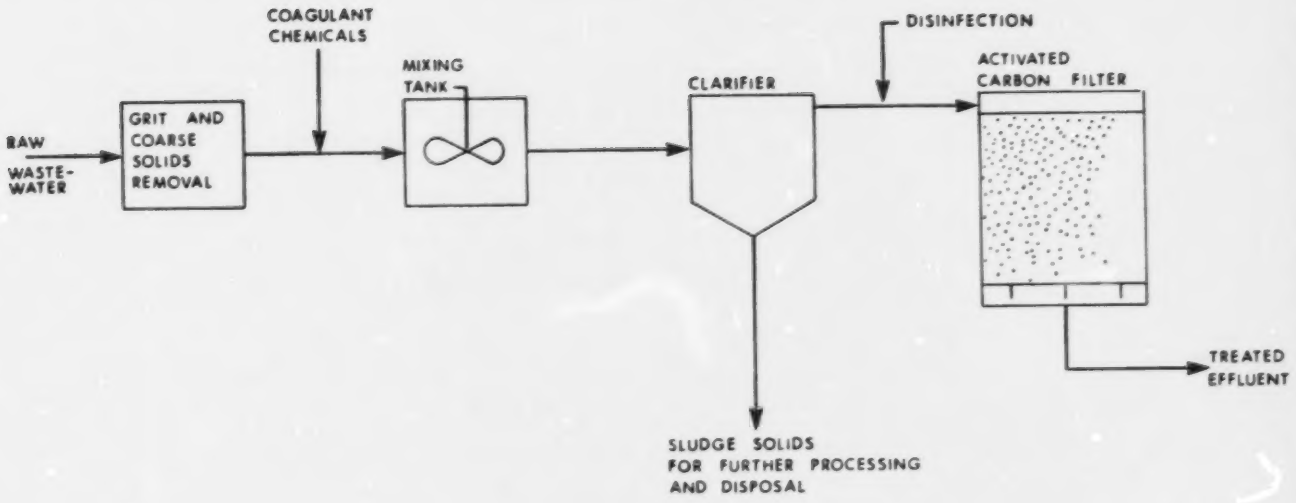


Figure 3.6

SCHEMATIC FLOW DIAGRAM OF THE PHYSICAL CHEMICAL PROCESS

3. consistently good performance when properly operated;

4. able to handle wide fluctuations in loading, particularly when equalization basins are used ahead of the plant; and

5. at full efficiency from the day they are put in use since they do not depend on the establishment of a microbial environment.

Disadvantages reported by the same authors include:

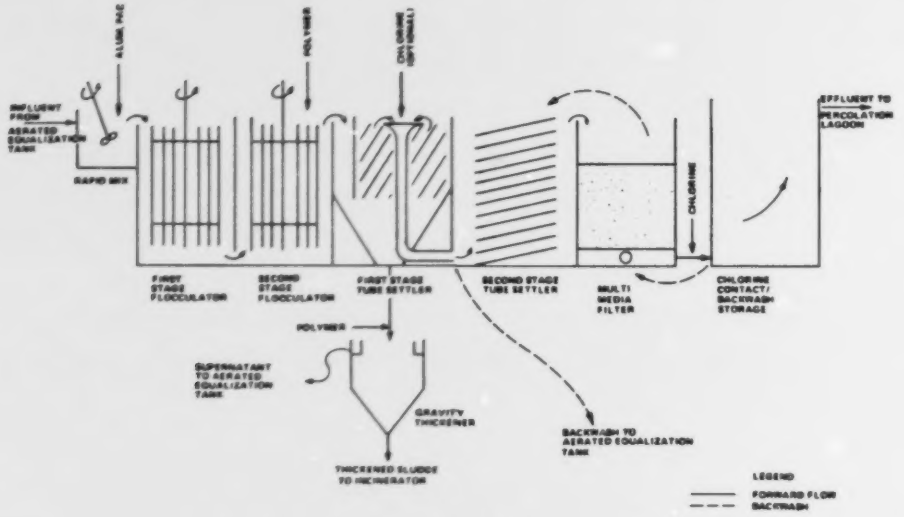
1. the need for skilled operators able to provide relatively constant attention to plant operation;

2. high operating costs associated with chemicals, electrical energy and labour; and

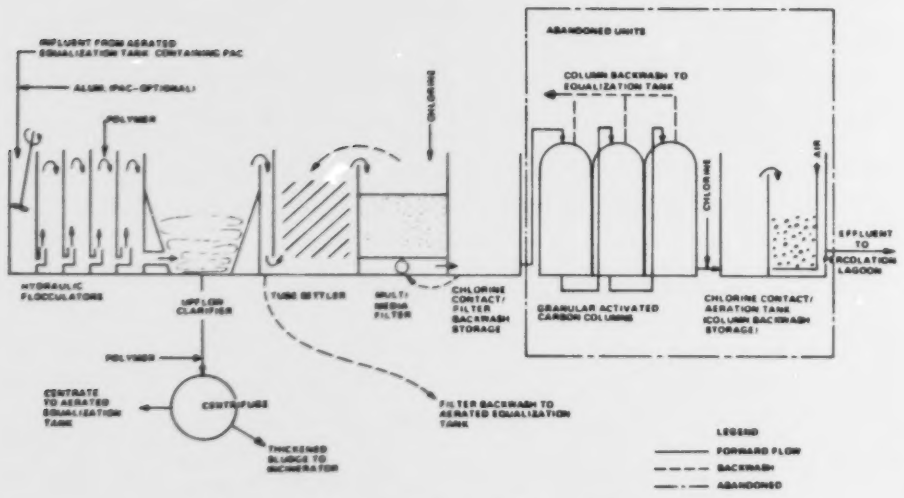
3. production of large quantities of chemical sludges requiring disposal.

A number of these plants were installed in construction camps for the Trans Alaska oil pipeline constructed in the mid 1970's. Eggener and Tomlinson (1978) reviewed three years of experience in the operation, modification and maintenance of 36 of these plants. Plant sizes ranged from 30 to 946 m^3/day (8,000 to 250,000 gal/day) and were located in construction camps ranging in size from 200 to 3,500 beds.

Two types of physical-chemical package plants were evaluated. A simplified process diagram for each is illustrated in Figure 3.7. The first type was designed to use powdered activated carbon for adsorption of dissolved organics while the second was designed to use granular activated carbon filters for organic removal. Both types were preceded by screening or comminertion of raw sewage and aerated flow equalization tanks. Lined emergency holding ponds, designed to hold five days flow, were constructed to hold untreated wastewater or excess sludge. Treated effluent was discharged to percolation lagoons. Sludges and screenings were dewatered and incinerated.



PHYSICAL CHEMICAL UNIT A



PHYSICAL CHEMICAL UNIT B

Figure 3.7

FLOW DIAGRAM OF CONSTRUCTION CAMP WASTEWATER TREATMENT SYSTEMS (Eggener and Tomlinson, 1978)

The authors reported a number of operational problems with these plants which necessitated mechanical alterations including the abandonment of the granular activated carbon filters because of anaerobic growths in the beds. The deposition and caking of sludges in flocculators, tube settlers and centrifuges necessitated constant operator attention. They concluded that the typical plant required full-time attendance by at least one operator. Once the required plant modifications had been made and operator experience was sufficient to provide skilled operation, the plants were able to achieve at least 85 percent removal of BOD and suspended solids concentrations were consistently reduced to less than 5 mg/l.

The same authors evaluated the operation of physical-chemical plants in parallel with extended aeration plants and concluded that although the extended aeration plants were more sensitive to large flow variations, they did not require full-time operators, were less complex mechanically, used fewer chemicals and produced less sludge.

In commenting on the application of physical-chemical treatment systems in the Arctic, Smith (1986) suggested that "physical/chemical treatment should only be considered if very high effluent requirements exist in conjunction with site conditions that preclude other forms or combinations of treatment.

3.3.6 Other Wastewater Management Alternatives

The previous discussion has reviewed the wastewater treatment alternatives most commonly used in the Arctic and High Arctic both in small coastal and inland communities and at work camps or construction camps.

There are a number of other solutions to wastewater management in the Arctic and High Arctic which have either been used on a limited basis or have been proposed for consideration.

Land application of raw or partially treated sewage or industrial effluents has received widepsread acceptance in more temperate climatic zones, particularly

because of its relatively low cost of operation and the opportunity to recycle nutrients and water for crop production. Its suitability is obviously more restricted in cold climates, particularly the Arctic.

Sletten (1977) evaluated the suitability of land application in permafrost areas through experimental studies near Fairbanks, Alaska. Aerated lagoon effluent was applied at high rates (5.5 to 152 metres/yr) and low rates (0.6 to 5.5 meters/yr). He concluded that:

1. Results from the slow rate system indicated that drinking water quality could be achieved; and

2. The high rate system was considered to be more feasible for cold climate conditions than low rate application because the need for winter storage was less, the system did not rely on vegetative uptake and the free draining, coarse-textured soils necessary for such systems were often found in alluvial valleys and coastal areas where many Arctic communities are located.

He suggested that for most wastewater constitutents, high rate systems were capable of sustained, effective performance in extreme climates.

James (1980) reported the use of a tundra disposal system at Pangnirtung, NWT. The system, which was under construction at the time of his report, involved the dumping of trucked sewage, including honey bags, into a holding tank where it was macerated. Floatables were skimmed off and the liquid overflow was discharged to the tundra with the aid of a spreader. The sewage flowed downhill through the tundra some 200 meters before reaching the ocean. A similar system was under construction at Spence Bay, NWT at the time.

Pollen (1985) reported that the most common final disposal method for package plant effluents from petroleum production camps in the Prudhoe Bay area was direct application to the tundra. During the winter, the effluent accumulated as ice, often forming mounds which had to be cleared occasionally to keep the

outfall open. During spring break-up, the effluent thawed along with the snow. He reported that the tundra provided a natural tertiary treatment system since the nutrient-poor vegetation removed virtually all of the residual BOD, nitrogen and phosphorus within a few hundred feet of the outfall. Fecal coliform bacteria which survived during the winter were destroyed quickly during the 24-hour daylight of the summer months. The same author provided a more detailed description of these results in another paper (Pollen, 1983).

Smith and Christensen (1982) reported the disposal of moderately dilute wastewater from Fort Franklin, NWT to a forested area. Land disposal systems were also reported for the communities of Destruction Bay and Waston Lake in the Yukon. Disposal to percolation basins was reported for Faro and Teslin in the Yukon and Fort Good Hope, Detah, Enterprise, Fort Resolution and Pine Point in the NWT. Moderately dilute wastewater is discharged to a forested area at Fort Franklin and treated effluent from Watson Lake, Yukon is discharged to land at high rates.

In some cases, such as Hay River and Pine Point, lagoon effluents are discharged to swamplands where further polishing and nutrient removal are assisted thorugh plant uptake. Several other communities (Yellowknife, Baker Lake and Rae-Edzo have converted existing lake systems into wastewater treatment systems.

Septic tanks, one of the oldest methods of sewage treatment have been used successfully in the Alaskan Arctic (Reed et at, 1984). The author reported that although the failure rate for these systems was high, particularly in the Fairbanks area, the typical failure was not due to freezing but to faulty design, faulty construction, carryover of solids from an improperly maintained septic tank, or excess infiltration of surface water due to improper site drainage. They reported that seepage pits were more commonly used than the conventional tile field since they are more compact, have less horizontal surface area and therefore have the potential for greater thermal efficiency. These effluent disposal systems are unsuitable, of course, in those regions where permafrost is near the surface. Subsurface disposal systems also require that the soils be

fairly porous in nature in order that they not create a major hydraulic stricture. Where these latter constraints are absent, septic tank and subsurface disposal systems offer a potential solution, particularly for shore-based work camps.

More exotic approaches to wastewater management have included treatment of wastewaters to sufficiently high quality to allow direct recycle of the water for non-potable reuse. For example, Pollen (1985) reported that the effluents from some of the treatment plants on the North Slope of Alaska were reused as shop water, toilet flush water or for diluting drilling chemicals and muds. In all cases, innovation was used to utilize the resource potential of sewage effluents while eliminating direct discharge to the physical environment.

Brown et al. (1975) described the preliminary design of a sewage treatment system for the Arctic which would be capable of providing complete recycling of treated effluent. The treatment system selected was based on the wet air oxidation process and reverse osmosis and evaporator processes were used in conjunction with ozone and ultra-violet disinfection to provide water of drinking water quality. Wet air oxidation is a chemical reaction occuring in a liquid phase between oxygen and suspended or dissolved combustible matter. The reaction is exothermic and, provided sufficient organic matter is present, sufficient heat is liberated to maintain a self-sustaining reaction and to provide excess heat for energy recovery. While the plan which was developed appeared feasible, particularly for isolated settlements where both water supply and waste disposal pose dual constraints, the concept was not developed to a pilot plant or field installation stage. No cost benefit data were available in the report.

Bouzoun (1983) evaluated the application of a modified hydroponic system to provide treatment and polishing of wastewater. He described a process called the nutrient film technique (NFT) in which the author used various species of plants, including cattails, reeds, cucumbers and reed canary grass. A film of wastewater only a few millimeters deep flowed through the root mat of plants which grew, without soil, on an impermeable and slightly inclined surface. The system was housed in a greenhouse in order to provide a longer growing season.

The NFT system differed from a hydroponic system primarily in the depth of wastewater. In a hydroponic system, the plant roots are completely inundated. The very shallow wastewater depth in the NFT system provided several advantages:

1. a portion of the roots could be immersed in the source of nutrients while the remaining roots were exposed to atmospheric oxygen;,

2. the root mat acted as a very effective filter for the insoluble suspended solids; and

3. the immersed portion of the root mat provided an excellent site for micro-organisms to attach themselves.

Previous researchers (Jewell et at, 1982) had also illustrated some additional advantages which made the process attractive for northern climates:

1. because the wastewater temperature increases significantly in the NFT units, heat pumps could be used to advantage to extract reusable energy; and

2. the large quantities of water vapor transpired by the plants could be condensed and recovered as pure water.

Bouzoun (1983) reported several experiments designed to evaluate treatment efficiencies and design criteria for an NFT system treating relatively cold (11^{o}C) primary effluent. Removal rates were in the range of 81% of BOD, 75% of total suspended solids, 30% of the total nitrogen and 21% of the total phosphorus.

Dietrick (1983) proposed a technique to inject sewage from oil and gas production camp support facilities into the exhaust stream of gas or liquid fired turbines. Injection into the stack exhaust plenum was preceded by screening to remove coarse solids. The author indicated that while the concept was technically feasible, further work was needed to define the bacterial emissions which might be present in the exhaust plume.

3.4 SURVEY OF EQUIPMENT SUPPLIERS

In order to gain a further assessment of the types of waste treatment package plants currently used in the Arctic, questionnaires were sent to Canadian manufacturers and suppliers of package sewage treatment equipment. While it was not possible to cover absolutely all existing or potential suppliers in Canada, twenty-five questionnaires were sent out. Ten companies responded by indicating they had supplied package treatment plants for Arctic installations. Five of these supplied some plant statistics.

These results have been summarized in Table 3.9. They confirm earlier comments regarding the predominance of extended aeration package plants.

None of the respondents supply physical-chemical plants. One respondent provided information on an oxidation ditch which is functioning satisfactorily in Alaska. Information was also submitted on aeration equipment for use in lagoon facilities. A copy of all supplier information has been supplied under a separate cover.

3.5 CAPITAL AND OPERATING COST ESTIMATES

3.5.1 Capital Costs

Figure 3.8 presents a summary of current (October, 1986) capital cost estimates for sewage treatment facilities of various sizes ranging from 4,000 L/d to 150,000 L/d. The costs are, of necessity, general in nature. Site specific requirements and/or constraints may render some packages or processes more costly to install. The cost estimates for pre-engineered package plants include the purchase price, approximate freight, installation and on-site costs. No allowance is made for sewage collection or pumping systems.

TABLE 3.9 - RESULTS OF SUPPLIER SURVEY

Process	Supplier or Manufacturer	Range of Capacities Available (L/d)	Location of Units	Number of Units	Operator Hours/Day
Extended Aeration					
	Aer-O-Flo Manufacturing	3,800-380,000	James Bay	32	0.5-1.0 (2 responses)
			Tuktoyaktuk	1	
			Alaska	NA	
			Sub-Arctic	100 +	
	H.D. Fowler	2,300-450,000	Tuktoyaktuk	1	
	Sanitherm Engineering	11,400-57,000	Alaska	2	
			Sub-Arctic	8	
Contact Stabilization	Aer-O-Flo Manufacturing	95,000-380,000	N/A	N/A	0.75 (1 response)
Rotating Biological Contactors					
	Petwa	7,600-570,000	Arctic	22	0.75-4.0 (2 responses)
	Aer-O-Flo Manufacturing	3,800-450,000	N/A	N/A	
	CMS Rotordisk Inc.	5,400-100,000	James Bay	8	
			Sub-Arctic	NA	

NOTES:

1. Sub-Arctic is defined as areas south of the $0^{\circ}C$ mean annual temperature isotherm.
2. NA means "information not available".
3. Number of operator hours/day usually depends on the extent of automation built into the plants.

Cost estimates for package plants assume that the following components are included:

1. comminutor;
2. primary clarifier (where applicable to the particular process);
3. aeration tank and equipment (in the case of suspended growth systems);
4. media, pumps, tanks and distributors (in the case of fixed film systems);
5. secondary clarifier;
6. aerobic sludge digester; and
7. sludge wasting mechanisms.

Cost estimates for treatment lagoons assume that they provide 12 months storage and incorporate the following components:

1. inlet and outlet piping and structures;
2. synthetic liner; and
3. fencing and civil works.

If no synthetic liner is required for the lagoon, then the capital costs would be reduced by approximately 30% to 40%.

3.5.2 Operating Costs

Operating costs are a significant factor in the selection of a sewage treatment plant for the Arctic. Experienced operators are not readily available, power costs are high and spare parts and manufacturer's service personnel are expensive to obtain.

The treatment process with the lowest operating cost is the lagoon system. The lagoon requires occasional inspection of the embankments and outlet piping to ensure no leakage is occurring. Operation of the outlet valve is required at the time of draining the lagoon. The annual cost, primarily labour, is estimated to be $2,500, and is relatively independent of lagoon size, particularly for the size of lagoons covered in this report.

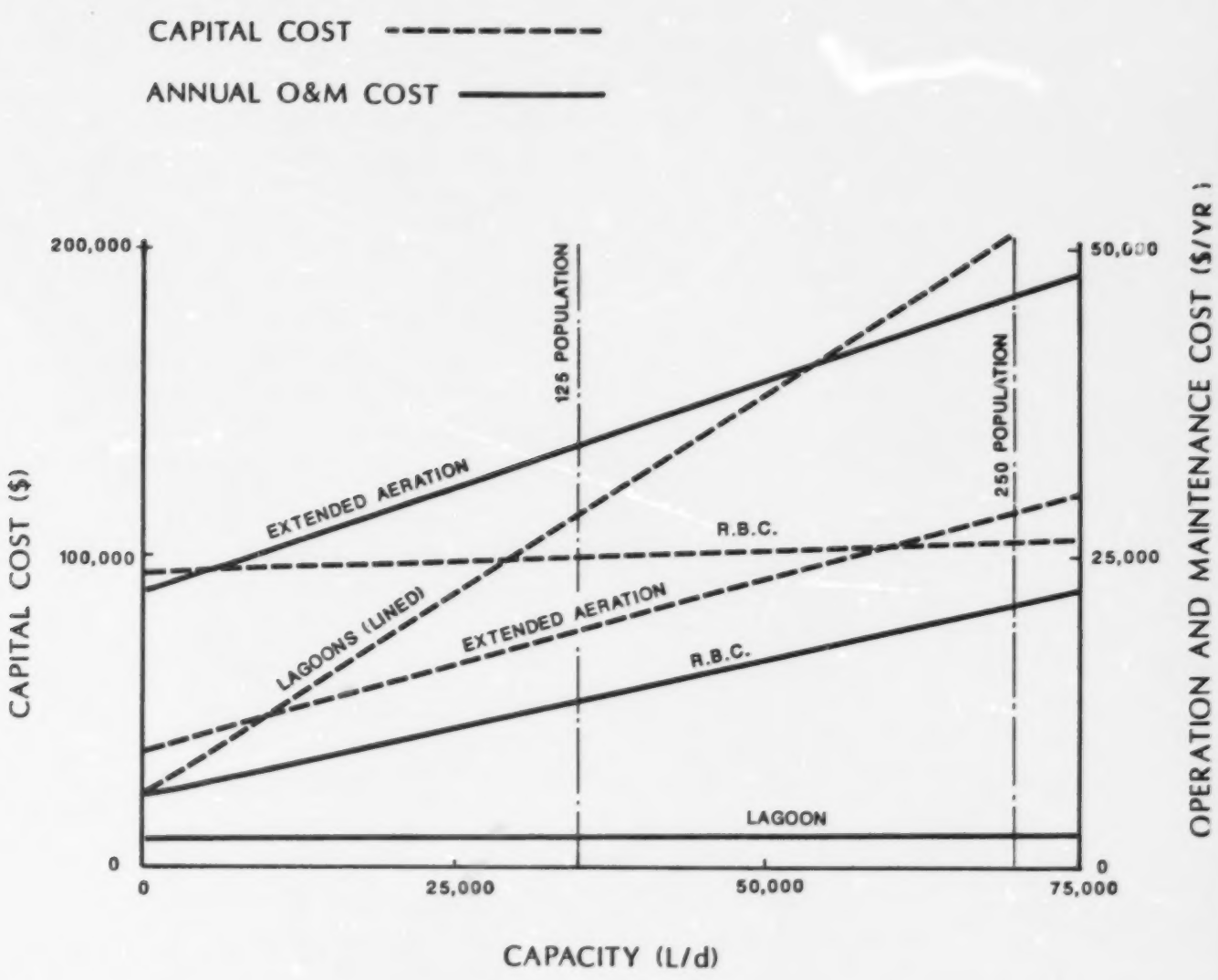


Figure 3.8

SEWAGE TREATMENT PLANT
COST ESTIMATES

Comparison of costs for fixed film systems (RBC's) and suspended growth systems (extended aeration) shows that the main difference is in the number of hours of operator attendance required. The extended aeration system requires more attention because it incorporates a sludge recirculation feature. The RBC system requires the sludge to be drawn off so that less operator awareness of the process is involved, and less attention is needed. The extended aeration process is more sensitive to changes in sewage quality and quantity, and this also calls for more operator attention.

Based on the assumptions that the RBC system requires one hour of attendance per day, and the extended aeration system requires three hours, the annual operator costs are approximately $11,000 and $33,000 respectively. The power costs for RBC systems will be less than for extended aeration systems. Assuming an annual power cost of $500 for each installed kW of power, costs for RBC's will vary from $1,000 to $4,000 per year, depending on the size of the unit. Equivalent costs for extended aeration units will be $2,000 to $8,000. The annual cost of spare parts can be assumed to be 5% of the capital cost for both RBC's and extended aeration units.

3.6 SUMMARY OF APPLICATION AND DESIGN CONSIDERATIONS

Current sewage treatment practices in Arctic onshore and offshore sewage treatment facilities range from maceration only to full secondary treatment followed by chlorine disinfection. Maceration followed by direct discharge to the ocean is restricted to drillships. Island or shore-based facilities utilize complete sewage treatment systems. For some shore-based facilities, lagoons are an effective and low cost solution. Their application and design criteria were summarized in Section 3.2.

In most oil and gas exploration camps in the Arctic, package sewage treatment plants are most frequently used. The most common types currently in use are some form of extended aeration system. These are followed closely in popularity by RBC systems. Both are biological treament processes which have certain

inherent weaknesses which must be overcome in order for the plants to operate successfully:

1. Biological processes are subject to upset by the high peak hydraulic loadings which often occur in work camp situations; therefore, aerated surge tanks play an extremely important role in maintaining plant stability; basins sized to accommodate 50 percent of the daily flow during three peak periods each day have been recommended (Froese and Heuchert, 1984).

2. Biological treatment process components (aeration basins, blowers, RBC media) must be properly sized to handle the sewage volumes and strengths anticipated. There is a tendency to undersize most plants because of unexpected high strengths of most sewages from work camps and because of the large variations in both strength and flow volume throughout the day. Tables 3.1 and 3.2 provide some useful design data.

3. The design should incorporate suitable sludge handling and disposal systems. This would include, in most cases, a sludge digester followed by final disposal either by direct discharge to the sea, by incineration or by disposal to a landfill. This last alternative also requires dewatering of the wet sludges prior to disposal. Froese and Heuchert (1984) recommended aerobic digesters sized to provide a sludge retention time of at least 15 days at a sludge concentration of 1.5 percent.

4. Clarifiers should be sized to accommodate the large peak hydraulic loadings characteristic of work camp facilities. Froese and Heuchert (1984) recommended oversizing the clarifiers to accommodate peak flows which are 2.5 times the average daily flow.

5. In most, if not all applications in the Arctic and High Arctic, mechanical treatment plants should be housed in order to provide freeze protection, both from the standpoint of maintaining process efficiency, as well as, for the protection of mechanical equipment and structure.

6. Plant design should provide an allowance for the purchase and onsite storage of key components of the treatment plant. This would include such items as motors, air blowers, pumps and bearings. The shipment of equipment to many remote Arctic locations usually involves lengthy delays.

7. The manufacturers of package treatment plants must be encouraged to provide equipment which is easily transportable to the Arctic. In many cases, the only form of freight transportation to either the shore-based or offshore sites is by aircraft.

The major requirements from an operational standpoint are the need to select operators to run these plants who are dedicated to their job and then to provide relevant and ongoing training programs for these staff. These training programs could be provided cooperatively amongst various owners with the use of regional rather than site-specific training courses.

The most significant operator-related problems which have been reported for package plants operating in the Arctic include the following:

1. snow and ice accumulation on structures, control equipment, roads and walls,
2. excessive cooling and freezing in unprotected aeration basins and clarifiers,
3. failure to scrape hopper - type clarifiers regularly,
4. failure to operate sludge returns,
5. insufficient operational time for blowers in activated sludge systems,
6. operation of plants by unskilled and poorly motivated personnel.

There is generally a need for good data collection and evaluation programs for sewage treatment plants in the Canadian Arctic. This is important for both the development of appropriate effluent guidelines as well for the design of treatment plants for future facilities. Monthly grab sample results are insufficient to provide reliable design data. Grab samples collected at a frequency of at least once weekly or 24-hour composite samples collected

weekly provide much more reliable research results. Where good design practices and sound plant operating procedures are followed, high quality effluents have been produced from offshore and shore-based facilities in the Arctic.

The major limitation of all biological treatment processes is the requirement for a start-up period before they become fully functional. They are inappropriate, therefore, for facilities that only operate for a month or two at a time before shutting down. In such cases, physical-chemical treatment plants are much more appropriate. They have no characteristic start-up period.

4.0 ENVIRONMENTAL EFFECTS OF TREATED AND UNTREATED SEWAGE DISCHARGES INTO ARCTIC MARINE WATERS

4.1 INTRODUCTION

This section outlines the general environmental setting of Arctic marine waters and the potential and expected impact of discharging sewage effluent from a submarine outfall. The review considers both liquid and sludge disposal and comments on the environmental changes, if any, that might result from secondary or tertiary treatment, as well as, from discharging untreated sewage.

4.2 FACTORS INFLUENCING DISPOSAL OPTIONS

4.2.1 General

In order to assess the impacts of discharging raw or partially treated sewage to Arctic marine waters, it is important to recognize the physical processes which are a part of the Arctic environment. Parameters which will strongly influence the movement of sewage effluent include wind/waves, currents, density stratification (thermoclines, pycnoclines), sedimentology and ice.

The following section outlines each of these physical features and how they may influence disposal options or operating conditions. The main regions considered in this report are the Beaufort Sea, Mackenzie Delta and high Arctic coastline. Extensive literature surveys of the physical and biological environment, including species lists, were prepared as background to the Beaufort Sea Environmental Impact Statement (e.g. Anon. 1982D, 1982E; Welch, 1980). This brief summary highlights some of the major factors as they relate to marine sewage disposal.

4.2.2 Waves

Waves are generated only during the open-water season, which occurs from approximately mid-July to mid-October. Despite this short open-water season,

waves are a significant modifying process within the coastal zone. Open-water characteristics are as follows (Harper et al., 1985):

1. **background waves** that are less than 1 m in height account for less than 30% of the annual wave energy and occur 78% of the time;
2. **intermediate storm waves** that are 1 to 2 m in height, account for nearly 50% of the annual wave energy and occur 20% of the time; and
3. **severe storm waves** that are greater than 2 m in height, account for 20% of the annual wave energy and occur less than 2% of the time.

The dominant wave-approach directions in the Beaufort Sea indicate that most of the storm-wave energy originates from the northwest. Wave action is important in sediment transport, especially in shallow, exposed sites. Solids may build up for extended periods at certain times of the year, but one major storm event can be sufficient to completely move or mask the material that has accumulated.

The extent to which the sediments are influenced by wave action is dependent on both the water depth and the height and period of waves. A wave with an amplitude of 0.75 m and a period of 5-7 s (mean Beaufort summer wave) will have a major influence on the bottom sediments in depths of a few metres, but will have no significant effect on sediments deeper than approximately 20 m. During storm events, however, the maximum water depth that can be affected by the waves will also increase.

4.2.3 Currents

Tidal currents are small in the Canadian Beaufort Sea (Fissel and Birch, 1984) and currents in the shallow coastal areas are driven primarily by winds and the discharge of rivers such as the Mackenzie River. Local current patterns will vary, depending on coastal orientation and configuration. However, in shallow waters, currents are typically in the order of 50 cm/sec. Bottom currents in deeper waters (greater than 20 metres) are much lower, typically less than 30 cm/sec (Anon. 1982C).

Currents will play a major role in the dispersal of effluent and associated solids discharged to marine waters. The strength and direction of the currents present, the existence of a density layer and the season all will be factors in assessing the environmental impact.

Once solids have settled, their redistribution and ultimate fate depends upon several factors. The most important is the strength and duration of bottom currents. However, the degree and rate of deposition by natural sediments and the ice cover characteristics must also be considered, especially in shallow coastal waters.

In calm sea conditions or during times of ice cover, discharged solids will settle directly around the outfall. However, during summer (open water) conditions, storm wave action will tend to resuspend some of this material, and the solids may be mixed in with, or buried by, material eroded from a coastline and/or by sediment from rivers such as the Mackenzie.

During freeze-up, ocean currents are typically very slow and movement of solids is minimal, although there may be some ice scour in shallow areas. Considerable scouring will occur, however, during break-up, during summer ice-flow movement, and during freeze-up.

4.2.4 Sea Ice

Most of the Arctic Basin is covered with an ice pack having an average thickness of 3 m. In the Beaufort Sea, the pack ice moves in a clockwise gyre. Open water develops in the late summer in the southern Beaufort Sea and Mackenzie Delta although many of the straits and channels between the Arctic Islands (e.g., the northwest passage) remain clogged with large, multi-year ice floes. They are, at best, navigable by non-icebreaking vessels only for a six to eight week period in August and September (Anon. 1982C; Environment Canada, 1983).

Sea ice occurs in various stages of development - young ice (less than 30 cm thick), first-year ice (30-200 cm), and multi-year ice (greater than 200 cm

thick). Sea ice will move in response to currents and winds. Areas of open water are created when ice moves apart, while large pressure ridges, up to 10 m high, may form when large ice masses converge.

Sea ice reforms annually and limits the open-water season to approximately three months (mid-July to mid-October). The presence of sea ice also effectively limits wave activity to these three open-water months. The presence of pack-ice offshore further restricts wave action, even during the open-water months, so that much of the Arctic is a comparatively low wave-energy environment.

There are three principal ice zones in the Arctic: landfast ice, a transition zone, and the polar pack ice. Landfast ice, which will have the greatest influence on waste disposal, is anchored to the shoreline or sea bottom by ridge keels and is more or less stationary. It grows out from the shore to approximately the 20 m water depth contour by mid-February. This ice is usually less than a year old and measures 1 to 2 m in thickness.

The polar pack in the Beaufort Sea is comprised principally of multi-year ice, which includes heavily-deformed ice such as rubble fields and which rotates clockwise around the Beaufort Sea at an average rate, at its edges, of approximately three kilometres per day.

The transition zone, generally made up of first-year ice, lies between the polar pack and landfast ice and is a particularly dynamic area.

4.2.5 Suspended Sediment

Suspended sediment concentrations in the southern Beaufort Sea can vary from less than 0.1 mg/L to more than 100 mg/L (Bornhold, 1975; Dunbar, 1970). High suspended sediment levels are associated with the Mackenzie River plume, particularly inside the 10 m bathymetric contour.

The estimated long-term (10,000 years) consolidated sedimentation rates in the Beaufort Sea off the Mackenzie Delta vary between 2-3 mm/year in depths less than 10 m, to 1-3 mm/year in 10-20 m of water, and 0.5-2 mm/year in 20-40 m (Harper and Penland, 1982).

Sedimentation of suspended solids will provide a "clean" cover over solids and may enhance the biological recovery of the area.

4.2.6 Physical Oceanography

The Mackenzie River is a major influence on the oceanography of the shallow Beaufort Sea. The low salinity/water temperature of the water creates a permanent pycnocline over the delta waters during freshet and summer months. Generally, the pycnocline will decrease in an offshore direction. Plume thickness, as defined by the pycnocline depth, can vary from 2 to 10 m.

This pycnocline will influence the distribution of smaller-sized particles. Disposal of effluent below the pycnocline would help to confine the dispersion of the discharged material. If the effluent is discharged above the pycnocline, the likelihood of greater dispersion increases, due to the more active near-surface flow.

4.2.7 Seasons

Winter runs from October to March or early April and is a period of little or no solar radiation and increasing thickness of sea ice. Because of the ice cover, water circulation is restricted, with little or no exchange with the atmosphere (e.g., oxygen). Salinity, in general, increases during this period except near the Mackenzie Delta. Dispersion of effluent discharged beneath the ice will be at its minimum during the winter.

Spring begins in April and during the first months (to May) is similar to winter except for increasing solar radiation. Currents under the ice are weak and salinity is probably greatest during this period. During late spring (May to July),

landfast ice begins to melt and a large influx of often turbid river runoff from snow melt enters the marine coastal waters. Solar radiation is high and the combination of fresh water and higher temperatures results in very highly stratified waters in some areas. As the ice melts, and suspended sediments enter the system, solids deposited on the bottom will be mixed and/or buried. The density structure of the water column will influence the effluent plume, depending on where the outfall is located.

Summer (July to September) is when break-up of sea ice occurs. Solar radiation is decreasing, while salinities start to increase as the melt water subsides. Summer is the period when most of the wind-driven mixing of the water column occurs, including wave-induced erosion and deposition of sediments. Primary production is greatest during this period, as would be recreational and other uses of the shoreline and waters. However, this is also the period when the effluent would receive the greatest degree of dispersion and dilution.

Fall runs from September to October. The decreasing solar radiation and falling temperature results in slush ice developing along the shore. Salinity becomes restricted as sea ice becomes more extensive.

4.3 CHEMICAL AND BIOLOGICAL BACKGROUND

4.3.1 Nutrients and Phytoplankton

Nutrient levels in the ocean are affected by plant uptake, in situ regeneration (e.g. excretion), upwelling of deeper waters, resuspension of sediments, and terrestrial runoff. Arctic waters usually become stratified during late spring and summer because of temperature and water salinity variations. The nutrient supply near the surface may become exhausted by phytoplankton growth, although in regions of high sediment loads and turbidity plumes (e.g. Mackenzie River), phytoplankton growth may be light-limited (Grainger, 1975). Nutrients are primarily replenished from deeper waters when wind-generated currents disrupt the stratification and cause vertical exchange with deeper waters below

the photic zone. However, the combination of a short season of intense light and the predominance of stratification during open water makes the Arctic Ocean and adjacent waters one of the least productive areas of the world (Dunbar, 1970; Platt and Subba-Rao, 1975).

Phytoplankton populations in the Arctic generally develop during late spring and summer, as ice cover recedes and solar radiation increases. In general, Arctic phytoplankton communities are dominated by diatoms, particularly in the near shore regions and in the earlier portion of the summer period. Pennate diatoms predominate early in the open water season while centric diatoms are more abundant later in the summer and in early fall. In the open ocean waters, which frequently show low nutrient levels during the late summer, flagellates are most abundant (Anon. 1982E).

The species composition and abundance of phytoplankton communities in Arctic waters are highly dependent on seasonal and local differences in the physical-chemical environment. These differences, in conjunction with biological factors such as grazing pressure, contribute to seasonal patterns of succession. In nearshore areas, high concentrations of suspended sediment, relatively low salinities, warm temperatures, and an adequate supply of nutrients associated with freshwater discharges characterize the environment. In most cases the limiting factor to phytoplankton growth in these areas is the light intensity (Grainger, 1975).

In offshore areas, the stratified nature of the water column effectively prevents nutrient replenishment from deeper waters. Low light intensities exist in areas of persistent ice cover, and the availability of nutrients is restricted following the initial uptake by spring phytoplankton blooms. In general, phytoplankton growth in offshore waters is restricted by nutrient availability, particularly nitrates (Grainger, 1975).

4.3.2 Zooplankton

Zooplankton are responsible for much of the secondary production that occurs in Arctic marine waters. Many species are herbivorous and form a direct link to vertebrates such as fish and seabirds. However, most Arctic food webs involve four or five energy transfers through herbivorous and carnivorous zooplankton and fish to seabirds or marine animals.

Some zooplankton species found in the Arctic Ocean complete their life cycle in one year, although life cycles of two or even three years have also been reported. Most herbivorous zooplankton species reproduce during the late spring and summer when phytoplankton abundance is highest (Anon. 1982D, 1982E). Local enhancement of primary production may result in an increase in zooplankton biomass, but the effect is likely to be masked by water circulation except in very enclosed areas.

4.3.3 Epontic (Under Ice) Community

Epontic organisms are species which inhabit the bottom few centimetres of ice and the under-ice surface. It is believed that this community plays a major role in high-latitude ecosystems because it extends the growing season, thereby adding to the annual production of organic matter at a time when planktonic algae are rare. The utilization of the relatively abundant epontic fauna by fish, especially Arctic cod, and other carnivores (seals, seabirds), while not well-documented, suggests the community is an important link.

The epontic flora is generally dominated by colonies of pennate diatoms, which inhabit the brine cells in the interstices of the ice crystals. At maximum density (May), the community may be a layer several centimetres thick. Dinoflagellates, flagellates and cryptonionads form the remainder of the epontic microalgal community. Centric diatoms are generally rare (Anon. 1982D, 1982E).

Considerable variability can be expected in the epontic flora due to differences in depth of overlying snow cover, differences in the timing of the bloom, or nearby freshwater inputs.

A variety of fauna have been observed from the under-ice community, including heliozoans, hypotrichous ciliates, nematodes, turbellarians, polychaete larvae and harpacticoid copepods. However, the most common invertebrates are the gammariid amphipods.

Diver observations and theory suggest that the fauna feed heavily on the epontic flora during the period of the year when there are few alternative food sources. The under-ice community may also play an important role in the life cycles of many invertebrates by providing food in a protective environment for juvenile stages (Anon. 1982D, 1982E).

The epontic algal community may contribute as much as 25 to 30 percent of the total annual primary production in the Arctic, but its main importance is probably associated with the timing of this production, which occurs six to eight weeks prior to significant phytoplankton blooms.

4.3.4 Benthic Invertebrates and Macro-Algae

Benthic invertebrates represent an important link between primary producers and top-line preditors. They traditionally have been grouped into two broad categories - infauna and epifauna. Infaunal organisms are generally found within the bottom sediments. Some even exhibit preferences for a narrow range of sediment grain sizes. Infaunal organisms are usually sedentary, and once established, may persist in the same location from year to year. Examples of the infauna include oligochaetes, polychaetes, bivalve molluscs, echiuroids, and sipunculids.

Epifauna generally inhabit the upper surface of the substrate, although some may burrow for brief periods. This group is further divided into sessile or mobile forms. Sessile epifauna are attached to solid surfaces such as rock or cobble,

wood, metal, kelp or other materials. Examples of sessile epifauna include barnacles, hydroids, anemones, bryozoans and mussels.

The mobile epifauna category is dominated by crustaceans, including amphipods, mysids, cumaceans and decapods, although echinoderms and gastropod molluscs are also prominent members of this group. The mobile epifauna are well represented in the Arctic and are more prevalent than the sessile epifauna. They form a substantial portion of the diet of many fish species (Anon. 1982D, 1982E).

While the database is far from complete, there appears to be a general trend toward greater infaunal diversity and density with increased distance offshore, at least to the edge of the continental shelf (200 m). They are generally not well-established, however, in shallow estuarine areas or in the main ice scour zones (down to 5-10 m). They also decrease markedly in very deep (greater than 1,000 m depth) waters.

Mobile epifauna occupy the nearshore areas during the open water season while there appears to be an active emigration of species to deeper water during winter.

Macro-algae are limited in distribution. They are restricted by the availability of suitable substrates such as rocky shores, and by the scouring action of landfast ice. Species present are similar to those from more temporate latitudes - kelp (Laminaria and Alaria) are often dominant (Anon. 1982D, 1982E).

4.3.5 Fish

The species composition of the fish community during the open water season is closely related to differences in salinity, temperature and ice conditions. Marine species are associated with cold saline water while anadromous species (fish which spend part of their life cycle in fresh water) inhabit the brackish, coastal environments. Occasionally during the open water season, freshwater species can be found in coastal areas adjacent to river mouths and deltas.

During the ice cover period, there is a marked change in species composition along the coastal habitat. Anadromous fish are confined to freshwater inland environments or deep channels in the deltas, while the marine species are found offshore (Anon. 1982D, 1982E).

Far fewer species (40-50) exist in the Arctic Ocean compared to more temperate waters (over 300). This factor is a function of low temperatures, low overall biological productivity and extensive ice scouring which precludes use of shoreline habitat. Overall, the most common species found in coastal waters are the Arctic cisco, least cisco, fourhorn sculpin, Arctic char, Arctic cod, starry flounder and whitefish (Anon 1982D, 1982E). Of these the latter four are most commonly harvested by native fishermen.

4.3.6 Birds and Mammals

A variety of seabirds and mammals inhabit the Arctic environment, especially during the spring and summer. Descriptions on their abundance, migrating patterns and habits can be found in review documents associated with Beaufort Sea Hydrocarbon development plans (Anon. 1982D, 1982E).

Apart from the potential of some organic toxicants to be bio-concentrated in the food chain, such as has occurred with DDT, there have not been any documented adverse impacts on birds and mammals associated with marine sewage disposal. Effluents are usually discharged from subsurface outfalls where they become diluted and dispersed rapidly.

4.4 POTENTIAL CONCERNS

4.4.1 General

The discharge of raw or treated sewage to marine waters may impact the environment, due to constituents within the effluent. The degree of impact will be a function of the concentration of contaminants in the effluent, the

background levels of the receiving environment, and the mixing and dispersion capacity of the receiving environment.

For purposes of this study, the effluents to be discharged from on-shore and off-shore camps and communities will consist primarily of domestic wastes. Industrial contaminants such as complex organic compounds, chlorinated hydrocarbons (e.g. PCBs, various pesticides), or significant quantities of trace metals are absent. Typical constituents of these effluents were described in Section 3.

The principle constituents of sewage, and summaries of their potential environmental effect are as follows:

1. **Organic Matter** - Microbial degradation of organic compounds may lower the dissolved oxygen concentration of a receiving water;

2. **Settleable Solids** - Settling solids could alter particle size distribution of the sediments, thereby altering benthic community structure; the decay of organic sediments may result in localized anaerobic conditions and overlying waters, thereby altering the distribution of benthic organisms.

3. **Inorganic Nutrients** (nitrogen and phosphorus) - An increase in available N and P could increase primary production, thereby altering trophic level interactions, increasing organic material to the sediments (see Item 2), or decreasing dissolved oxygen levels in the water column and sediments through microbial degradation of plant biomass.

4. **Pathogenic Organisms** - Disease-causing bacteria and viruses can be transferred through the receiving water environment.

5. **Residual Chlorine** - As described in Section 3, one common method to reduce the levels of pathogenic micro-organisms is to use chlorine as a biocide; any residual remaining in the effluent following discharge may be toxic to fish.

6. **Suspended Solids** (turbidity) - The discharge of sewage can create a turbidity plume which may reduce the amount of light available for plant photosynthesis; turbidity may also affect fish migration patterns.

7. **Floatables** - non-gradable or slowly degradable materials such as plastics and rubber, fats and oils, are less dense than sea water and will rise to the surface, if discharged. The effects are largely aesthetic (visual pollution or offensive odours) although fat globules may contain large concentrations of bacteria and excessive oil spills may endanger sea birds.

The following sub-sections discuss more specifically the actual or potential environmental effects of each of these constituents, particularly as they apply to the Arctic marine environment.

4.4.2 Organic Matter and Settleable Solids

One of the major constituents of sewage is dissolved and particulate organic matter. The actual concentrations of each are a function of the sewage source and the degree of treatment provided prior to discharge. The degree and type of treatment the sewage receives will largely dictate the amount of particulate matter discharged. As described in Section 3, lagoons or other secondary treatment processes are capable of removing at least 85% to 95% of the suspended material while tertiary treatment removes most if not all of the residual following secondary treatment. However, disposal of the solids that are removed, known as sludge also has to be considered when assessing the impact of effluents, particularly where ocean disposal of these sludges (either by barge or through an outfall) is practiced.

As already noted in Section 3, the organic strength or BOD of raw sewage can be quite considerable and is one of the concerns associated with waste disposal. Microbial respiration and the oxidation of ammonia, hydrogen sulfide, methane and iron compounds will all deplete oxygen levels while the replenishment of oxygen will come from photosynthesis, reaeration and mixing.

The environmental impact of the effluent will be a function of the degree of dilution and dispersion. In general, if effluents are well-diluted, the organic loading is likely to have little effect on dissolved oxygen levels in the receiving water. Because of the very high assimilative capacity of most ocean environments, ocean disposal has been widely supported, even for primary effluents (Mearns, 1981; Carter, 1973; Calvert, 1975; Officer and Ryther, 1977; Reish, 1984; Waldichuk, 1984; Ellis, 1984; Stewart, 1984; Waldichuk, 1985). If well mixed, the decrease in dissolved oxygen is likely to be small, and the effect measurable only in the localized region around the effluent plume (Topping, 1976). For example, the total annual input of organic material discharged to the North Sea (over 500,000 tonnes) consumes less than 1% of the oxygen present at any one time (I.C.E.S., 1974).

On the other hand, the discharge of sewage to some areas, expecially enclosed bays and estuaries which have limited flushing, can result in fish toxicity problems. Studies near a sewage treatment plant in Vancouver, British Columbia (Birtwell, et al, 1983) suggested that the toxicity of sewage effluent, as determined from in situ bioassays, was primarily a function of very low oxygen levels (less than 2 mg/L). Water quality criteria generally recommend that dissolved oxygen not fall below 5 mg/L and preferably remain above 6-8 mg/L (EPA, 1976; Davis, 1975). Low dissolved oxygen levels (20-25% saturation) in Hong Kong Harbour (Preston, 1975), were attributed to poor flushing, and a recommendation was made to reroute the effluent to open coasts via an outfall.

Low oxygen levels in parts of the Baltic Sea (Svansson, 1975; Larsson et al., 1985; Rosenberg et al., 1977) were attributed to the loading from organic matter and to climate variations. These effects were aggrevated by the accumulation of natural material and a very low water exchange in the areas most affected.

A spill of untreated sewage into San Francisco Bay (which normally received tertiary treatment) resulted in a lowering of dissolved oxygen to near zero with significant fish kills. However, within a month after its occurrence, water quality and oxygen levels had returned to normal levels (Cloern and Oremland, 1983).

In contrast to the situation which occurs in shallow bays or estuaries, outfalls located in deep, well-mixed waters generally exhibit no adverse effects. Water samples collected near outfalls off southern California and in Puget Sound, Victoria Harbour and from the City of Vancouver showed little or no oxygen depletion (Bascom, 1982; Mearns, 1981; Drinnan and Clark, 1980; Balch et al., 1976).

Any effects of raw sewage disposal are likely to be most strongly exhibited in the benthos (Reish, 1984). Solids deposition creates a highly enriched organic substrate which can affect the benthic organisms that would normally inhabit the area. The magnitude of change in species will be a function of the degree of deposition (e.g. smothering), the rate of decomposition of the organic matter, the presence or absence of toxic materials and changes to sediment characteristics (smaller particle size or increased organic content) which favour certain species over others.

Pearson and Rosenberg, (1978), have identified five zones of influence within the benthos:

1. an abiotic zone;
2. a zone of opportunists, with high numbers but few species;
3. a zone where abundance decreases and is low, but diversity is high;
4. a transition zone to typical (unstressed) communities; and
5. typical communities.

Most frequently, three stages are noted:

1. a stressed or polluted area surrounding the end of the pipe;
2. an intermediate or semi-healthy community; and
3. a healthy or normal community, unaffected by discharge.

Species changes have generally been correlated with high organic content of the sediments (Cederwal and Elmgren, 1980).

These changes have been documented for a wide variety of discharges in different coastal environments. The severity of impacts varies considerably, however. For example, the severely degraded area may range in size from only a few metres to several kilometres from the outfall. Many studies have shown changes from sensitive species towards more tolerant (of organic substrates) species (Lizarraga-Partida, 1974; Gray, 1976) and, in particular, an increase in the dominance of deposit feeders, especially the polychaete Capitilla capitata (Cederwall and Elmgren, 1980; Poore and Kudenov. 1978; Anger, 1977; Word et al., 1977; Spies, 1984), and a decrease in other species such as molluscs (Pearson and Rosenberg, 1978). Meiofauna generally increase in abundance in high organic sediments, although signs of stress (defined as the ratio of nematodes to copepods) were recorded near one large outfall (Vidakovic, 1983).

Studies conducted near five large outfalls in southern California (total discharge of approximately 4 billion litres/day) found areas which showed signs of some "impact" in the sediment ranging in areal extent from less than 1 km^2 to approximately 100 km^2 (Mearns, 1981). "Impact" was defined as an increase in deposit-feeding infauna. However, only 12 km^2 (less than 1% of the total area of the southern California Bight) was considered "degraded." This area had a very dense benthic community, high in biomass and numbers but low in species and diversity (Bascom, 1982).

High organic loadings may also result in a significant decrease in the oxygen content of the interstitial (pore) water of the sediment and in the waters immediately above the bottom. In severe cases, the sediment may become anoxic, with an increase in hydrogen sulfide, a highly toxic compound (EPA, 1976). Sulfides, in fact, may be the most important abiotic factor affecting the benthos (Mearns, 1981). This change in the chemical environment of the sediment is believed to be a major factor in the observed decrease in the number of species present near some outfalls (Birtwell et al., 1983; Bascom, 1982; Mearns, 1981; Poore and Kudenov, 1978; Botton, 1979; Vaccara et al., 1981; McGreer, 1982).

A number of studies have looked at the impact of sewage sludge on the marine benthos. Sludge from sewage treatment plants located in industrial urban communities was found to be the major contributor to heavy metals in fine sediments (Norton et al., 1984) and the toxicity of sludge was believed to be a function of chemical contaminants rather than its organic composition (Guarino et al., 1977). Other reports, however, found little change in metals concentrations in the sediments in an area near Philadelphia used for sludge disposal (Gunnerson, 1981; Guarino et al., 1977).

Several researchers have reported oxygen levels in bottom waters near sludge dumping grounds to be high and near background levels (McIntyre and Johnston, 1975; Norton et al., 1981). The initial effect of sludge dumping was a stimulation of oxygen consumption in surface waters and in the pycnocline, but oxygen concentrations returned to background levels within six hours (Thomas and O'Reilly. 1981).

Reviews of the environmental impacts of sludge disposal (Spies, 1984; Boesch, 1982) suggested that the benthic community that develops may have a greater capacity to oxidize organic material but may be less suitable to support higher trophic levels. Another study (Champ and Park, 1981) recommended that sludge be deposited in deep water, offshore, although it was acknowledged that the biota in those environments may be more sensitive to change because they are accustomed to a relatively stable environment (consistent temperature, salinity, chemical composition). Guarino et al. (1977) concluded that proper ocean disposal of sludge was not detrimental to the environment and should continue as a more appropriate means compared to landfilling or incineration. The contribution of nutrients and metals to the North Sea from the 10^7 tonnes of sludge dumped there annually, was found to be small compared to overall loadings from other sources (Lack and Johnson, 1985).

Sludge disposal in shallow waters may result in an accumulation of organic matter and the onset of anaerobic conditions. This in turn, may result in a decrease in the benthic population (Norton et al., 1981; Vaccara et al., 1981), although increases in some fish species have been recorded near outfalls and

sludge disposal sites (Mearns, 1981). Several authors suggested that the detrital food chain in the plankton would be enhanced by sludge disposal in deep water, due to the longer descent rate and horizontal dispersion, but with only slight, if any, changes in the benthic community (Vaccara et al., 1981; S.C.C.W.R.P., 1976; Smith, 1981). In general, however, the impact of sludge disposal on water quality was considered transitory, with little change in oxygen levels, nutrient concentration, or dissolved metals. Particulate metals were higher after the sludge was dumped, but the effects were short-lived (a few hours to days) (Pearson and Rosenberg, 1978; Anger, 1975; Lack and Johnson, 1985; Norton et al., 1984).

A review of possible monitoring parameters to detect the presence and impact of sludges dumped in the ocean (O'Connor et al., 1985) found that nutrients, total organic carbon, total suspended solids and most trace elements could not be used as indicators. Only the metals lead, iron and zinc, PCBs, and the steroid coprostanol were found to be in sufficient concentration in these sludges that they could be used as tracers. It is important to note that these sludges came from plants serving industrialized urban areas. It is unlikely that any of these contaminants would be present in the sewage generated at shore-based and offshore work camps. A recent review of ocean dumping of sludge (NOAA, 1984) concluded that present knowledge is sufficient to design suitable disposal systems for both sludge and final effluents, providing that control of industrial contaminants at source is carried out. Wide dispersal at adequate offshore distances was preferable environmentally, to containment in specific ocean sites.

Results from the few studies which have been carried out in Arctic environments do not contradict the basic conclusions of the preceeding work. Measurements made in Cook Inlet and near the communities of Anchorage and Frobisher Bay (Murphy and Miller, 1968; Murphy et al., 1972; U.S. Army Corps of Engineers, 1979; Heinke and Deans, 1973) did not show any oxygen depletion resulting from the discharges of raw sewages to the Arctic Ocean. In ice-covered waters, however, a significant decrease in oxygen content may result especially in localized and confined areas (Schallock et al., 1970). The impact of organic material on oxygen levels is reduced by the fact that BOD rates are considerably

reduced at the lower water temperatures (Murphy and Miller, 1968; Schallock et al., 1970; Fonselius, 1978).

4.4.3 Nutrients

Plant growth, both plankton and macroalgae, requires several inorganic elements, with nitrogen and phosphorus generally considered as the most important. Excessive plant growth, often referred to as eutrophication, can result in a number of adverse environmental effects such as: low oxygen levels, changes in species diversity, and finally, decreased aesthetic and recreational appeal.

The impact of nutrients to a water body develops through a series of stages (Webb, 1981; Parsons, 1984). Initially, the addition of nutrients will increase overall biomass in the primary, secondary and tertiary trophic levels. Further nutrient additions may produce species changes at all trophic levels and stimulate a greater input to the environment of fecal pellets and dying individuals not grazed, thereby stimulating benthic productivity. Any significant increase in concentration of detrital matter, and the associated microbial decomposition in the sediments may reduce dissolved oxygen levels.

Plant growth is generally controlled by that nutrient which is in shortest supply, often referred to as the limiting nutrient. Once that nutrient is depleted, further growth is curtailed even though there may be an abundant supply of the other required nutrients. In fresh water systems, it is generally accepted that phosphorus is the limiting nutrient and control of the phosphorus loading in effluents is a successful means of lake and river management (Schindler, 1977; Minns et al., 1986; Vollenweider, 1971).

In coastal marine waters, the situation is less clear. Nitrogen has generally been found to be the limiting nutrient in oceans (Officer and Ryther, 1977; Ryther and Dunston, 1971; Goldman, 1976; Thomas et al., 1974; Nixon, 1981; Rosenberg,

1985; Thomas, 1969; Perry, 1976; Antia et al., 1963; Laws and Redalje, 1979; Topping, 1976; Reed, 1975), although some studies have indicated that in certain circumstances, phosphorus may be limiting (Perry, 1976; Lung, 1986; Schindler, 1981; Meyers and Iverson, 1981; Pomeroy et al., 1972; Chiaudani et al., 1980).

Which of the nutrients is, in fact, limiting can be the major factor in determining treatment options for sewage, since phosphorus is much more readily removed by conventional secondary treatment plants than nitrogen. In fact, secondary treatment will increase the level of inorganic nitrogen (ammonia, nitrites, nitrates) through the breakdown of organic matter. In N-limiting situations, therefore, treatment may actually stimulate phytoplankton production more than will untreated sewage (Officer and Ryther, 1977; Laws and Terry, 1983). For example, ammonia, one of the main constituents of treated sewage effluents, has been found to be stimulating to phytoplankton photosynthesis near outfalls (Parsons, 1984; Thomas et al., 1980).

If nutrient-rich sewage is discharged into the euphotic zone of open marine areas, local enhancement in primary production may occur under some circumstances. Bascom (1980) and Welch (1980) both suggested that this can result in concomitant localized increases in zooplankton production and biomass. If nutrient levels are increased more than threefold, some phytoplankton species may be inherently better adapted to take advantage of the extremely high nutrient levels, and therefore become the dominant species in the community. Topping (1976) suggested that when these species cannot be ingested by herbivorous zooplankton or are detrimental to predaceous forms, the species diversity of the zooplankton community may be affected. This may then be reflected elsewhere in the food web. However, it should be emphasized that a threefold increase in nutrient levels would rarely be achieved in a marine environment with adequate water circulation, except possibly in the immediate vicinity of outfalls. In adddition, any changes in the species composition of the planktonic community would be relatively localized, and since phytoplankton and zooplankton are continously transported into and out of well-circulated areas, the period of exposure to sewage effluent could generally be insufficient to cause regionally significant alterations in community structure.

In areas where the effluent is exposed to a high degree of mixing and dilution, the stimulating effect on plant productivity of either raw or partially treated sewage has been small to negligible (Cloern and Oremland, 1983; Bascom, 1982; Caperson et al., 1971; Drinnan and Clark, 1980; McIntyre and Johnston, 1975A; Laws and Terry, 1983; Wood, 1975; Berg, 1975; Aubert and Breittmayer, 1975; Reed, 1975; Pike and Gameson, 1970; Chen and Orlob, 1972; McIntyre and Johnston, 1975B; Kleppel and Manzanilla, 1980). Localized increases in primary production may occur, particularly when the area is partially enclosed as in a bay or estuary (Caperson et al., 1971; Lung, 1986; Thomas et al., 1980; Rastetter and Cooke, 1979; Thomas and Carsola, 1980; Hardy and Hardy 1972; Mabbett, 1975; Eppley et al., 1972; Chiaudani et al., 1980; Topping, 1976).

Studies in Cook Inlet and near Anchorage, Alaska (Murphy et al., 1972) did not predict eutrophication to be a problem, partly because light was often limiting, due to high background turbidity and short summers. Light was considered the limiting factor during the period of greatest potential impact - the initial spring development of under-ice populations. Nutrient addition through sewage discharge was not expected to have a significant effect (Grainger, 1975; Alexander, 1974). However, higher phytoplankton productivity, attributed to an increase in nutrients, was measured near an outfall at Helsintai, Finland (Gunnarson and Porisson, 1976). No information was available to indicate the relative importance of light availability for that location.

An assessment of the potential effects of sewage nutrients on the epontic community is hampered by the lack of direct research, although the effects of sewage on planktonic algae are well-documented and probably similar. Depending on location, epontic algae may or may not be nutrient-limited (Alexander, 1974; Grainger, 1977). There is also some evidence of heterotrophy (utilization of organic compounds through non-photosynthetic pathways) by some species (Horner and Alexander, 1972). Whether the presence of nutrients in sewage would stimulate further growth of the algae, or whether the community is light-limited, is not known.

4.4.4 Toxicity

The toxicity of municipal sewages as measured by standard bioassay procedures is dependent on the level of pretreatment and the type of treatment, particularly where chlorination is practiced. Chlorine may be a major contributor to effluent toxicity. For example, Singleton (1980) found that effluents from various secondary sewage treatment plants had 96 hour LC50 toxicities ranging from 21% to 100%. Dinnel et al. (1981) reported results which showed the average 96 hour LC50 values of Seattle's West Point chlorinated effluent to be around 15 to 16 percent, while chronic tests showed effects to gill tissue at an effluent concentration as low as 0.5%. Bucklay et al. (1976) concluded that because the effects of residual chlorine on salmon blood chemistry occurred at one percent effluent, but not at 0.3 percent, the acceptable concentration of effluent in sea water was less than one percent. Sea urchin sperm bioassays were much more sensitive than traditional fish bioassays, by 5 to 10 times, with 0.2 percent being the highest concentration which did not cause a toxic response (Dinnel, et al., 1981).

West Point effluent dechlorinated with sulphur dioxide was shown to be approximately half as toxic as chlorinated effluent (Dinnel et al., 1981). Residual chlorine was extremely toxic to sea urchin sperm cells, and it was estimated that effluent dilutions of 1500:1 (at a distance of 3 km from West Point outfalls) would still be toxic, if the chlorine present was free chlorine. However, the chlorine in effluent reacts quickly with ammonia (to form chloramines).

The relative toxicity of free chlorine combined with chloramines is not well known (Dinnel et al., 1981; Wharfe et al., 1981). Wharfe et al. (1981) found no evidence of any acute toxic effects of chlorinated effluent on a variety of marine invertebrates, although they acknowledged that eggs and juveniles may be more susceptable. The bivalve Macoma was not affected by chlorinated sewage although resettlement of larvae was thought to be influenced by the organic deposits of the sediment (McGreer, 1982). Salmon, however, were found

to be very sensitive within 4 km of the same outfall, although a shortage of oxygen in the water was believed to be a major factor (Birtwell et al., 1983).

Sewage effluents do not appear to be particularly toxic to pelagic species. Effluent concentrations between 15 and 100 percent have shown no ill effects (Esvelt et al., 1973; Swartz et al., 1984). Sea urchin sperm cells, however, appear to be more sensitive. Negative effects have occurred at effluent concentrations as low as 1 to 7 percent (Norton et al., 1984).

The 96 hour LC50 toxicity to fathead minnows of effluents from California outfalls ranged between 26.6% and 100%. The response of several invertebrates was about the same as the fish (Reish, 1984). On the basis of fish bioassays, Mearns (1981) suggested a minimum acceptable dilution of 333:1 for chlorinated effluents and 150-160:1 for unchlorinated or dechlorinated effluents.

Coralline algae showed enhanced growth when exposed to primary effluent, as did several other macroalgae species (Reish, 1984; Kindig and Littler, 1980). Kelp beds in California decreased in abundance due to effluents, but increased once source control of contaminants was instigated (Bascom, 1982; Mearns, 1981).

There are many references which study or review the toxicity of specific trace metals and organic toxicants such as pesticides. Several receiving water criteria for trace metals have been published (EPA, 1976; McKee and Wolf, 1963; McNeely et al., 1979; Demayo et al., 1978; Inland Waters Directorate, 1972). It is unlikely, however, that sewage effluents from the types of facilities covered in this report will contain any significant concentrations of heavy metals and organic toxicants. These are more prevalent in sewages and storm runoff from industrialized urban areas.

4.4.5 Human Health

A primary concern with the disposal of municipal wastes is the presence of disease-causing bacteria and viruses. Pathogenic organisms which have been isolated from sewage include:

1. polio, hepatitis and Herpes viruses;

2. typhoid, shigellosis and salmonellosis bacteria; and

3. a number of parasitic life cycles such as those which cause amoebic dysentry and beef tapeworm eggs.

The salmonella group of bacteria are by far the most common cause of infectious disease in temperate climates and are consistently present in sewage treatment plant effluents (Barrow, 1977).

The detection of specific pathogenic organisms is technically feasible but is impractical and financially prohibitive. Indicator organisms such as coliform bacteria (Escherischia coli or E. coli) are used therefore, to evaluate the presence of fecal pollution. Total coliforms include organisms found not only in the feces of man and animals, but also in soils and plant material. The fecal coliform test has been devised in order to differentiate more specifically those bacteria which reside in the intestines of warm-blooded animals.

The relationship between coliform numbers and the incidence of disease is unclear (Churchland, 1980) although a recent study of the beaches in New York City found a high incidence of gastroenteritis in bathers at beaches affected by sewage pollution (Cabelli, et al., 1979). Receiving water criteria assume that the higher the number of coliform bacteria in a water sample, the greater the risk of contamination from pathogenic bacteria or viruses. As a consequence, total and fecal coliforms are commonly used as standards for receiving waters. Current regulatory guidelines for recreational and consumptive use and for shellfish harvesting are based on these indicator organisms.

A review of water quality criteria for coliform bacteria was carried out by Churchland (1980). The most restrictive standard applicable for Arctic marine waters is that for shellfish harvesting (filter-feeders such as clams, oysters and mussels). Shellfish which may be eaten raw can concentrate bacteria in their tissues because they are filter feeders. Waters near shellfish beds must show a median fecal coliform level of less than 14 MPN/100 ml and not more than 10 percent of the samples can exceed 43 MPN/100 ml (Canadian Shellfish Safety Programs, 1977).

Federal guidelines for coliform levels in water used for swimming recommend a value of 200 MPN/100 ml (logrithmic mean) or less with no more than 10 percent of the samples to exceed 400 MPN/100 ml (Anon, 1983). Criteria for non-contact recreation (e.g. fishing, boating, picnicing, nature study) have not been established in Canada, partly because of the difficulty in establishing a relationship between coliform levels and disease caught during these activities. However, an average of 1000 MPN/100 ml (not to exceed 2000 MPN/100 ml) for fecal coliforms was suggested by the U.S. National Technical Advisory Committee (United States Department of the Interior, 1968). Both coliform bacteria and pathogenic organisms are considerably reduced by efficient sewage treatment processes, and in particular, by disinfection (EPS, 1985).

Several authors have reported that the survival of viruses and other pathogens may be longer than coliforms (Vasconcelos and Swartz, 1976; McFeters et al., 1974; Edmond et al., 1978). Studies carried out near two outfalls in Florida indicated that while the level of fecal coliforms was reduced by four orders of magnitude when untreated sewage effluent was compared with chlorinated secondary effluent, viruses were reduced only by two orders of magnitude (Edmond et al., 1978). The same study showed that proposed effluent standards for virus concentrations in the receiving waters were exceeded near untreated outfalls but not near outfalls receiving secondary chlorinated treatment.

Survival of coliform bacteria is much higher in the Arctic, primarily due to the cold temperature. Halton and Nehlsen (1968) reported that it took 35 days for a 99 percent reduction of E. coli at 0°C compared to less than a day at 20°C.

Studies in freshwater (Gordon, 1972; Van Donsel et al., 1974) found that fecal coliforms survived 2.7 to 5.4 times longer in a river in Alaska compared to winter survival rates in more temperate climates. Davenport et al. (1975) concluded that the maximum survival of fecal coliforms would occur at $0^{o}C$, under ice cover.

The effects of temperature and light on the survival rates of bacteria and viruses is especially important since the information could be used to predict levels during different times of the year. It is also important in the Arctic, where the low temperatures and lack of light for much of the year suggest a higher survival rate than in more temperate climates. Further discussion of survival rates of bacteria and viruses under Arctic conditions was addressed in the review of lagoon treatment in Section 3.

Microbial organisms have been associated with particulate matter from waste discharges (Bracewell et al., 1980; Grimes et al., 1984; Schaiberger et al., 1982). The particulates, which consist mainly of grease and wax, appear to protect the bacteria from chlorination and salt water (Grimes et al., 1984). Because these particulates are usually quite buoyant, they will tend to surface rapidly, even through density gradients. They are then susceptable to surface wind currents (Bracewell et al., 1980; Balch et al., 1976).

4.5 OVERVIEW OF IMPACTS

While the impact of domestic wastes has been long recognized for freshwater systems, and successful management techniques to combat the effects of organic loading and eutrophication have been developed (Schindler, D.W. 1977; Minns et al., 1986; Vollenweider, 1971) the same cannot be said of marine ecosystems.

Early recognition that large amounts of raw or partially treated sewage could alter the marine environment was related to changes in distribution for a variety of benthic organisms (Blegvad, 1932; Alexander et al., 1935; Bassindale, 1938; Stopford, 1951). Monitoring programs designed to assess the environmental

conditions around marine discharges began in earnest in the 1960's. These ranged from simple effluent toxicity studies to large-scale research projects. One of the more comprehensive projects was the Southern California Coastal Waters Research Project (SCCWRP) which looked at the impacts of a wide variety of contaminants on the coastal marine ecology (SCCWRP, 1976; SCCWRP, 1977; SCCWRP, 1978; Bascom, 1983; Bascom, 1981).

Bascom (1982) summarized the results of 10 years of study on the impact of nearly 4 billion litres of wastewater discharged each day from five outfalls. The main biological effect was with the benthos, where there was a decrease in species diversity but a large increase in biomass in localized regions around the outfall. Fin erosion, and some other chronic effects, were apparent on a number of fish species, none of which were collected commercially or by sports fishermen. No human sickness has ever been attributed to the discharges. In areas where management practices such as source control of contaminants was instituted, there was a noticeable recovery of the benthos.

Other researchers have also come to the same conclusion that the impact is generally localized, involves primarily the benthic community and is frequently reversible (Greene, 1976). A shoreline discharge in Australia was detectable only within 300 metres of the 2.6×10^8 l/d secondary effluent, primarily with the organic concentration of the sediments and a shift in benthic species present. Nutrients in the effluent contributed to an increase in micro-algae and bacteria in the sediments which, in turn, provided food for benthic filter-feeders and deposit-feeders (Poore and Kudenov, 1978). Similarly, the main impact of 500,000 l/d of untreated waste discharged into Ensinada Bay was a shift in species diversity in the benthos (Lizarraga-Partida, 1974), while increased abundance of a number of indicator organisms was the principal effect near an outfall from Seattle, Washington (Mearns, 1981). Several reports on investigations of waste disposal in Arctic waters concluded that the detrimental effect of sewage would be minimal (Clark et al., 1962; Heinke and Deans, 1973; Grainge, 1969).

As already noted, the environmental impact of sewage effluents and sludges in marine environments is primarily a function of the degree of dilution and dispersion. The following conclusions may be drawn regarding the effects of dissolved and suspended organic solids as well as inert suspended solids from raw or partially treated sewages:

- In deep and/or well-mixed waters where immediate dilution is likely to occur, the effects of discharging either raw or partially treated sewages or sludges appears to be minimal and are restricted to localized benthic effects at worst; ocean disposal of primary effluents has been supported by a number of researchers.

- Discharge of raw or poorly treated effluents to near shore areas, such as shallow bays and estuaries which have limited flushing and water movement, may result in fish toxicity and cause some alterations to the benthos including depressed oxygen levels; the magitude of these effects is again a function of the degree of dilution and dispersion.

- Proper ocean disposal of sludges has been suggested as a more appropriate means of disposal than landfilling or incineration (Guarino, 1977); a recent review of ocean dumping of sludge (NOAA, 1984) concluded that present knowledge is sufficient to design suitable disposal systems for both sludge and final effluents, providing that control of industrial contaminants at source is carried out. Wide dispersal at adequate offshore distances was preferable, environmentally, to containment in specific ocean sites.

Sewages, both treated and untreated, contain significant concentrations of nitrogen and phosphorus. In raw sewages, these are usually complexed as organic compounds. In biological sewage treatment processes they become mineralized and thus become readily available for marine plant growth.

It is generally accepted that nitrogen is the growth limiting nutrient in the marine environment. In such a scenario, secondary sewage treatment processes

may actually have a detrimental effect on eutrophication since they do little to remove nitrogen. They only convert it to a form which is more readily available.

The following additional conclusions may be drawn from the previous discussion of sewage nutrient effects:

- Sewage effluents have been shown to increase primary production in enclosed areas such as bays and estuaries.

- Experience from Alaska has shown that where seawaters contain significant background turbidity levels, phytoplankton growth is light limited rather than nutrient limited. This probably represents a situation typical of the Mackenzie Delta region of the Beaufort Sea.

It is apparent that the two most critical issues regarding disposal of sewages to marine environments are their toxicity and the survival of pathogenic bacteria and viruses. Sewage effluents, though somewhat variable in their toxicity, have been shown to be harmful to fish, particularly where chlorination is practiced. Toxicity of free chlorine is greater than that of combined chlorine. It would seem prudent, therefore, either to eliminate, where possible, the requirement for effluent chlorination or to restrict the residual to certain maximum levels such as the 1.0 mg/L limit imposed by the Great Lakes Regulations described in Section 2.

The following conclusions may be drawn from the discussion of potential human health effects from marine discharges:

- Pathogenic organisms which have been isolated from sewage include polio, hepatitis and Herpes viruses, typhoid, shigellosis and salmonellosis bacteria and a number of other parasites such as those which cause amoebic dysentry and produce beef tapewarm eggs.

- Survival rates for coliform bacteria are much higher in the Arctic, primarily due to the cold water temperature and the lack of ultra violet

light in the winter to provide natural disinfection. Researchers have concluded that the maximum survival of fecal coliforms will occur at 0°C under ice cover.

- Viruses appear to have better survival rates than fecal coliform bacteria. Chlorination has been very effective, however, in destroying most pathogens, particularly from secondary effluents.

- The chlorination of raw sewage is relatively ineffective since microbial organisms are usually entrapped within the particulate matter where they are relatively protected from chlorination.

This discussion of human health effects is particularly important for those areas where effluents are discharged near beaches or in bays where human activities such as bathing or washing of clothes occur during the summer. It is also important for those areas where slaughtering of sea mammals for food takes place in the water, particularly since the meat from their carcasses is often eaten raw.

4.6 APPLICATION OF RESULTS

4.6.1 Introduction

The previous discussion has provided a general review of the environmental effects of discharging raw or treated sewage effluents and sludges to marine environments. Much of the published information refers directly to results under temperate climate conditions with limited data specific to Arctic applications.

The following descriptions are an extrapolation of these results to Arctic and High Arctic marine waters according to three potential effluent sources:

1. sewage from marine vessels;
2. sewage from offshore exploration and production facilities; and

3. sewage from shore-based communities and facilities.

4.6.2 Impacts of Sewage Discharged from Vessels

A wide variety of vessels would be operating in the Arctic (primarily the Beaufort Sea) should oil development and production proceed. They would range from large ice-breaking tankers and ice-breaker support vessels, operating year-round, to smaller work boats, supply vessels and barges which essentially only operate during the four months of open water.

The total number of vessels operating in the Arctic may be as high as 200-250 (Anon, 1982B). Based on an estimate of 0.25 m^3/person/day, the total volume of effluent which may be discharged is estimated to be about 3,000-3,500 m^3, or about 4.8 to 5.8 x 10^5 m^3 per year (based on an average of 160 operating days/year/vessel (Montreal Engineering, 1979). The maximum volume is equivalent to a town with a population of about 5,000 people. The effluent would consist of flush water plus wastewater from showers, sinks and kitchen and laundry facilities.

Regulations related to effluents from vessels (Canada Shipping Act, Arctic Waters Pollution Prevention Act) restrict the discharge of sewage to open waters while a vessel is underway. Discharges are prohibited in harbours or enclosed areas.

The intention of the operators associated with hydrocarbon development in the Beaufort Sea is to have all sewage on-board the vessels treated in a small package treatment plant, with the sludge incinerated or landfilled (Anon, 1982B). With the small volumes associated with any one vessel (approximately 150 m^3, assuming 120 personnel and 5 days storage) and the mixing that would be achieved, little or no impact is likely to result even from the discharge of raw sewage. The stimulating effect of nutrients would likely be slight, at most, and very localized. There would likely be no concerns related to microbial

contamination of shellfish or recreational areas and the organic material would probably be rapidly assimilated or dispersed before reaching the benthos. Mixing would also be such that oxygen depletion would likely be negligible.

4.6.3 Impact of Sewage Discharged from Exploration and Production Facilities Offshore

The total number of wells drilled, under the long-term development plan, might range from 30 to 70 per year (Anon, 1982A). Each well takes an average of 75 days to complete, with approximately 50 personnel involved (Montreal Engineering, 1979). Effluents from these platforms consist of flush water, shower water, and wastewater from kitchen and laundry facilities. It is the intention of the operators (Anon, 1982A) that all effluent would receive secondary treatment. Production platforms, once drilling has been completed, would require very few personnel, but the treatment facilities would remain (Anon, 1982B).

Each drilling site must be considered independently. The volume of effluent would be about 10-15 m^3/day for each well or 750 to 1,125 m^3 over the duration of the drilling. The total discharge to the Beaufort, assuming 70 wells per year, would be the equivalent of a town of less than 1,000 people. Spread over the different production fields, and assuming that an outfall and diffuser are installed, the impact from discharging even raw sewage is expected to be negligible or minor with very small, localized effects.

The small effluent volume, if discharged from a submarine outfall, would probably have little or no effect on primary production or oxygen depletion. The quantity of solids (in raw sewage) would cover, at worst, a small portion of the sea bottom. There may be some human health concerns if the effluent reaches the shores of the artifical island. However, the effluent should be well-mixed during open waters, which is the only period that people would be present on the "beach." Effluent accumulating under the ice may have some impact on the epontic community during the spring and early summer, before break-up, but it is not known whether the effect would be stimulation (nutrients) or toxic (due

mostly to the effect of fresh water on marine organisms). In either situation, the impact is expected to be localized and would not be a concern with respect to the overall ecology of the region.

4.6.4 Impacts of Sewage Discharged from Shore-Based Communities and Facilities

The size of coastal communities could vary between a few hundred people to as many as 2,000. Shore bases associated with hydrocarbon development would have a population of 250 to 500, while the total population of the Beaufort Sea region could be as high as 20,000 to 30,000 (Anon, 1982A) if development proceeds. The total volume of sewage, assuming 0.25 m^3/day/person and maximum development rates, could reach 5,000-7,500 m^3 per day. The environmental effects of any discharge can only be determined on a site-specific basis; they are dependent on many physical and biological factors.

While there was very little information from studies specific to the Arctic, the review of the literature from other environments suggests the following potential concerns:

1. A decrease in dissolved oxygen from the breakdown of organic matter, which in turn, may affect the benthic species present; this may cause changes in fish behaviour, or in some cases fish kills due to anoxic conditions.

   In the Arctic, the small size of any one outfall is likely to result in negligible decreases in oxygen levels if dilutions of greater than 100 to 200:1 are achieved. Organic matter settling on the bottom may create a localized area of anoxic waters overlying the sediments, but only in areas with little or no circulation.

   Effluents discharged under the ice will not be as well mixed as in open water conditions. In certain confined areas, the organic loading could lower the oxygen levels in the water; such effects have been measured in Arctic rivers. Counteracting this effect is the fact that microbial activity

during this period is much slower than in more temperate waters because of the cold temperatures.

To mitigate against the possible impacts of lowered oxygen levels in the water, outfalls should be located so that the effluent plume can be dispersed, recognizing that this will take longer during the ice-covered periods. The location also must recognize traditional migration patterns of fish, many species of which follow along the coastline.

2. Accumulation of particulate organic matter in the sediments may alter benthic communities and affect benthic-pelagic trophic relationships.

Studies have shown that the impact of organic matter on benthic communities is generally an overall reduction of species but increased numbers and biomass. Deposit feeders, especially polychaetes, are favoured over filter-feeders such as molluscs. The size of this enriched or degraded area is proportional to the volume of solids discharged. Anoxic sediment conditions and abiotic areas occur only under severe organic loadings to regions with very restricted circulation. Reish (1980) predicted that volumes of primary effluent of less than 7,000 to 10,000 m^3/day could be assimilated in temperate, open coastal waters.

3. Effluents may increase the nutrient level of the waters thereby stimulating plant growth.

The review suggests that, while some enhancement has resulted from marine discharges of sewage, they are generally small. Large scale eutrophication problems are generally associated with the discharge of large volumes of effluent into confined areas, such as rivers or lakes, estuaries or enclosed bays.

Arctic marine waters are likely nitrogen-limited during the open-water season and light-limited during the rest of the year. The small volumes of effluent associated with even the largest outfall expected, are unlikely to

show measurable effects in overall primary production, except for some localized stimulating effects near the outfall.

It is also important to note that if eutrophication is considered a problem, the treatment of sewage will have only a limited impact. Unlike phosphorus, very little of the total nitrogen is removed by conventional secondary treatment processes. In fact, secondary treatment may further stimulate primary production because organic nitrogen is converted to forms more readily assimilated by phytoplankton.

4. Toxicity of sewage effluent to marine organisms.

Domestic wastes from Arctic facilities will consist of toilet flush water, shower water, and wastewater from kitchen and laundry facilities. It is assumed that trace metals, PCBs, pesticides and other contaminants will not form part of the effluent that will be discharged.

Chlorination of sewage increases its toxicity and, therefore, should be avoided unless there is a potential human health concern. While chlorination would only occur during the open-water season, it is also the period of greatest fish activity, and the period when juveniles are most likely present.

Effluents collecting under the ice may pose a problem if water movement and dispersion of the plume are particularly restricted, although adult fish are likely to avoid such regions. During open water, dilution should be sufficient that little or no interference with fish migrating patterns will occur.

5. Presence of micro-organisms may pose a human health concern.

The very low temperatures of the Arctic increase the survivability of most micro-organisms, including potential pathogenic species. Areas which might be used for body contact recreation or for traditional native

activities such as washing and slaughtering of marine mammals for food must be protected from any sewage plume, as should be any shellfish beds used, or likely to be used, by man. Methods to achieve this objective include longer and deeper outfalls to increase the dilution and dispersion, treatment to remove most of the microbial organisms present in the effluent, and/or chlorination.

4.7 CONCLUSION

In conclusion, it is important to emphasize that for the most part a discussion of environmental impacts of sewage effluents on the Arctic marine environment must rely primarily on results extrapolated from other marine environments located in temperate zones. As already reported in Section 2, there is a need to better evaluate the impacts imposed by the Arctic's unique characteristics, particularly in the Beaufort region - relatively shallow waters, low ambient water temperatures, low velocity currents and seasonal solid ice cover. While extrapolated data can be used to provide indicators, ongoing monitoring programs are required to test the assumptions used to draw conclusions.

5.0 STUDY RECOMMENDATIONS

5.1 INTRODUCTION

The last two stated objectives in the study Terms of Reference are as follows:

1. Make recommendations, based on the previously presented information, regarding the short and long-term discharge of sewages to Arctic marine environments; and

2. Identify and provide information on the optimal primary and secondary treatment systems that will operate efficiently and effectively in the north on a seasonal and year round basis.

The following is a presentation of our recommendations as derived from our previous discussion.

5.2 REGULATORY POLICIES AND GUIDELINES

The previous regulatory policies regarding sewage discharge to Arctic marine environments have fluctuated over the past 10 years. Firstly, there has generally been a shortage of good research results upon which to base any guidelines. Secondly, prior to the mid-1970's there was very little industrial activity in the Arctic and hence, little need to establish suitable research programs or effluent guidelines.

It is particularly timely to develop effluent guidelines for Arctic marine discharges at the current time since it is apparent that commercial production of oil and gas reserves is inevitable. The following recommendations are derived from our previous analysis presented in this report:

1. In certain instances, particularly in the case of drillships, it would seem prudent to continue the current policies which allow direct discharge of

raw sewage following maceration. As noted previously, the environmental impacts are likely to be negligible, particularly because of the relatively small quantities discharged from any particular ship.

2. For offshore and shorebase facilities it would seem prudent to follow the current "Guidelines for Municipal Type Wastewater Discharges in the Northwest Territories". These guidelines state that for effluent discharges to the sea the following should apply:

> "A site-specific study may be required for effluent discharges to the sea when the following may be affected: shellfish waters; waters used for fish propogation; waters used extensively by marine mammals; waters used for recreation; and confined waters.
>
> Such a study will also be required where the objectives are to be met by a long outfall or for a proposal to discharge sludge down the outfall. In cases where the boundary between marine and estuary conditions is in question the outfall length is to be determined site-specifically by appropriate current and dilution studies."

3. Where site specific studies suggest that effluent treatment beyond maceration is required in order to protect the receiving environment, the guidelines should require a minimum of secondary treatment with disinfection to be included where human health concerns are important.

4. These secondary treatment guidelines should emphasize the use of "Best Practicable Technology" rather than setting specific effluent limits. In other words, the regulatory agencies should act as catalysts towards the use of proper design standards in the sizing of treatment works, in the selection and design of suitable treatment processes, in the development of regional plant operation training programs and in the collection and review of plant operating data. Tools which might be developed to achieve these

objectives include a Standards and Design Manual For Sewage Treatment and the development and administration of a regional sewage treatment plant operator training program for Arctic installations. The Cold Climate Utilities Manual (Smith, 1986) provides the basis for a good design manual. Studies have shown that where the design of sewage treatment plants includes certain key components described in Section 3 and where plant operators are given on-going guidance in plant control, most of these facilities are capable of meeting organic and suspended solids removals in the range of 90 to 95 percent or more.

5. Where the threat of contamination by pathogenic organisms is the only environmental concern, disinfection, usually by chlorination, should be preceded by full secondary treatment. As explained in Section 4, disinfection of raw and even primary effluents is relatively ineffective since most bacteria and viruses are entrapped by the suspended solids.

6. Since the chlorination of effluents raises a toxicity concern for any receiving waters, we suggest that where disinfection is specified, an upper limit should be placed on the allowable effluent chlorine concentration. For example, the Great Lakes Regulations have used an upper limit of 1.0 mg/L.

5.3 BEST PRACTICABLE SEWAGE TREATMENT TECHNOLOGY

5.3.1 Process Selection and Design

Sewage treatment practices in the Arctic range from no treatment at all to complete tertiary treatment prior to release of effluents. The most common form of sewage treatment currently used in the Arctic is the screening or maceration of raw sewage followed by discharge to holding basins for release to the receiving environment.

Lagoons, primarly anaerobic and facultative types, are also relatively common in the Arctic. They are simple and relatively inexpensive to operate, are able to handle variable waste characteristics and flows and, when properly sized, are capable of providing relatively high quality sewage. Their use is quite obviously restricted to land-based work camps and communities.

Mechanical sewage treatment plants, particularly the smaller self-contained package plants have found application primarily in work camps associated with off-shore and on-shore petroleum exploration and production activities. The most commonly used processes include contact stabilization, extended aeration, RBC and physical-chemical plants. All have some common features which make them particularly suitable for these specific applications:

1. they are relatively compact and can be easily shipped to site as complete units; and

2. when operating properly, they are capable of providing full secondary and in some cases, tertiary treatment of sewage.

Where biological treatment package plants are used to provide secondary sewage treatment, the following components should be included within the design:

1. Aerated surge tanks should be included in the plant design because of their importance in maintaining plant stability; basins sized to accommodate 50 percent of the daily flow have been suggested.

2. Plants should be properly sized to handle the sewage volumes and strengths anticipated. Tables 3.1 and 3.2 provide some useful design data.

3. All treatment systems should include suitable sludge handling and disposal systems.

4. Clarifiers should be sized to accommodate the large peak hydraulic loadings characteristic of work camp facilities. Best success has been

achieved with clarifiers which are sized for a flow of 2.5 times the average daily flow.

5. Mechancial treatment plants should be housed in order to provide freeze protection, both from the standpoint of maintaining process efficiency as well as for the protection of mechanical equipment and structures.

6. Plant design and procurement should make allowance for the purchase and onsite storage of key components such as motors, pumps, blowers and bearings.

7. Package plant design should allow for easy transport of the equipment to site by aircraft.

Smith (1986) stressed the need for particular attention to operation and maintenance factors during the process selection and design stages for Arctic sewage treatment plants. Specific examples which he suggested included:

1. Alarm systems to signal process failures such as power outage, tank overflows, excessive sludge accumulations, etc;

2. Good air circulation and heat distribution within heated enclosures to minimize the risk of localized freezing;

3. Attention to expected winter ice and snow depths to ensure easy access to all critical components;

4. Intermittently used facilities must be winter protected;

5. Protection of electrical equipment from burn out due to power failures and voltage variations;

6. Control panels and sensitive switches must be isolated from the moisture-laden plant atmosphere to avoid malfunction due to icing or chemical corrosion.

In general, because of lengthy start-up requirements, biological treatment processes are inappropriate for facilities that only operate for a month or two at a time before shutting down. In such cases physical-chemical treatment plants are much more appropriate since they have no characteristic start-up time requirements.

In addition to these most commonly used sewage treatment processes, we have reported the evaluation and in some cases on-site experimentation and full-scale application of sewage handling options which have unique potential for the Arctic and High Arctic. They may generally be classified into two categories:

1. those which utilize to maximum benefit, the receiving environment itself, to provide sewage renovation; and

2. those designed to use directly the resource potential of the sewage.

Examples in the first category which were described in Section 3.3.6 include:

1. surface application to soil, particularly where free draining, coarse textured soils are found;

2. disposal to the tundra on a continuous year-round basis;

3. treatment in septic tanks and subsurface disposal to tile fields, seepage pits, or media filters, either aerobic or anaerobic;

4. direct discharge to forest land and swamp land for further removal and uptake of nutrients by plants; and

5. injection of sewage into the stack exhaust plenum of liquid or gas fired turbines.

Innovative approaches to the extraction of the resource potential from sewage include:

1. reuse of treated effluents as shop water, toilet flush water or drilling mud dilution water;

2. mechanical treatment using the wet air oxidation process to provide recycling of water and recovery of process heat;

3. the use of a nutrient film technique, a modified hydroponic system which provides reusable heat and generates high purity water through evaporation and transpiration processes.

5.3.2 Treatment Plant Operational Requirements

From an operational standpoint, the major requirements are the need to select conscientious plant operators and to provide ongoing training programs for those staff. The most common operational problems encountered in Arctic sewage treatment plants include the following:

1. senstivity of plant processes to large fluctuations in sewage flows and strength;
2. corrosion and other high humidity problems caused by the need to provide housing of treatment facilities as protection from the harsh winter climate.
3. snow and ice accumulation on structures, control equipment roads and walls.
4. excessive cooling and freezing in unprotected aeration basins and clarifiers,
5. failure to scrape hopper - type clarifiers regularly,
6. failure to operate sludge returns,

7. insufficient operational time for blowers in activated sludge systems,
8. operation of plants by unskilled and poorly motivated personnel.

Arctic operational experience with sewage treatment processes indicates that where mechanical sewage treatment processes are used, good operator training programs and frequent surveillance of plants are absolutely essential to achieve satisfactory performance. The system described by Pollen (1985) included on-site daily operational surveillance of a number of plants in a region, an operator training program presented twice yearly and monitoring of effluent quality on a monthly frequency. This three phase approach was reported by the author to be successful in achieving effluent qualities which were in compliance with plant requirements in each case.

The content of operator training programs for Arctic application need not differ significantly from those used in southern Canada with one exception. Emphasis should be placed on specific winter operational requirements and potential problems. Operator training is most effectively accomplished thorugh structured classroom and/or job-site training sessions provided by skilled professionals. Since there is a high turnover of staff in most work camp situations, particularly for the operation of sewage treatment facilities, these training sessions should take place at a frequency of at least once or twice annually.

In conclusion, there is a need for good data collection and evaluation programs for sewage treatment plants in the Canadian Arctic. This is important for both the devleopment of appropriate effluent guidelines as well as for design of cost effective sewage treatment facilities.

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